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Eighteenth Annual Convention.

Discussion at Buffalo August 21st. Papers by Lincoln, Haskins, Davis and Browne.

Mr. W. S. Barstow:—In the last paper, that of Mr. Browne, I was very much impressed, as a central station manager, with the special attention paid to the wattless energy in the starting of the motors. In large central stations, the one thing which is retarding to a very marked degree the development of the alternating current both for railway and for lighting, is the fact that you are required to have in the station such a large capacity compared with the horse power of the motors that are installed, as against that which it is necessary to carry with a direct current installation. Whether it will be possible for the station to secure an income from this "borrowed current,"—that is quite another matter to consider. In almost all cities there are both systems in existence, and the cost of the two systems, direct and alternating, are continually compared; so that we have the commercial problem of still getting a rental for the borrowed energy used in starting the motors, and at the same time keeping the customer's bill so that it will not suffer by comparison with that for the energy used in direct current motors. In other words, there are many cases all over the country where in one block a customer will use direct current service and in the very next block, or a short distance away, another customer, a friend of his, will have an alternating service, and they often compare their bills. That is one objection from the commercial side, but still I think that the central station ought to receive, in some way, as Mr. Browne has so appropriately put it, a rental for this "borrowed current."

The President:—I quite agree that it is not desirable to permit customers to receive this wattless power for nothing, but I do not agree with Mr. Barstow that it is inherent in andan essential of the alternating system, and of the alternating motors to overload the station in starting with excessive wattless currents. The wattless currents of the alternating motor especially when starting, are largely an incident due to the neglect of the station manager to guard against them. It depends entirely upon the motor whether excessive wattless currents exist. The alternating current induction motor can be made to start and operate with very moderate wattless current, but then it becomes slightly more expensive, and consequently if the station does not exercise any supervision and control, the customer buys the cheapest motor, and the manufacturer of motors is obliged to supply it, and such a motor will in starting take three or four and more times its full load current. This rather unfortunate feature is responsible for much of the trouble with excessive wattless currents and poor regulation in alternating motor circuits.

In the paper on "Power Factor Indicators," by Mr. Browne, is mentioned a way of charging for the wattless current by over-

compensating the recording meter. I had some experience with that. Quite some time ago, I believe in 1894, when a fairly large system was changed to alternating, a large factory was to be operated by induction motors, instead of the continuous current motors used before, which were of any ordinary kind. The bills for power with the induction motors were found very small compared with those for the continuous current motors, and the customer was willing to pay for the wattless current. The manner in which this was accomplished was by inserting in the potential circuit of the recording wattmeter an inductive reactance (instead of making the potential circuit as non-inductive as possible, as customary) adjusted so as to charge the desired percentage of wattless current, I believe 25 per cent. In this case the meter read high at highly inductive load, right at non-inductive load and low at anti-inductive load.

As an objection to the power factor indicator there has been mentioned the error due to the current in the potential coil lagging less than 90°, in consequence of its resistance. This objection has been overcome by dividing this current again into branch currents displaced from each other, for instance, by shunting the potential coil by non-inductive resistance. Hereby the potential current, as the more lagging branch current, can be adjusted to perfect quadrature with the main E. M. F.

MR. HASKINS:—I wish to remind the INSTITUTE that the question of charging (in the meter) for idle current was quite fully discussed before the INSTITUTE as early as 1897, at Greenacre. I think it was the sense of the discussion, that it was highly desirable, and perhaps feasible, to adopt a system contemplating an overcharge (on the watt basis) for inductive loads.

PRESIDENT STEINMETZ:—I am quite sure there is a good deal more to be said on the question of meters, and that many of you can give us a good deal of valuable information—for instance, Mr. Dunn.

MR. H. W. BUCK:—Referring to Mr. Lincoln's paper on the subject of the synchronism indicator, I have seen this device in operation at the plant of the Niagara Falls Power Company for some time, and from a practical standpoint I think the device very valuable. In the old days of small alternators, where the inertia of the revolving armature was very small, almost any device could be used as a synchronizer, for if the armatures were not in strict synchronism when paralleled, it took a very small amount of electrical power to jerk the armatures into step, so to speak, but with the large direct connected alternators which are at present being used, the amount of power required to synchronize the machines is something enormous, and unless the machines are thrown together at the point of exact synchronism, it takes a very large amount of synchronizing current, which is a severe electrical shock to the system, and a very great amount of mechanical power, which is a great strain on the

units. So that much more accurate methods of synchronizing are at present demanded than formerly, and for this purpose this synchronizer which has been described is, I think, the best device which has as yet been developed. A voltmeter can be used as a synchronizer, but it is not satisfactory, for the reason that the low readings of an alternating current voltmeter are not at all accurate, and therefore the exact moment of synchronism is not indicated, and the error is very considerable. Another objection to the use of a voltmeter is that the amount of power which operates the needle of the voltmeter is limited, and it cannot therefore be made very large. Mr. Lincoln's synchronizer which is practically an alternating current motor, can be made any size, so that the needles can be made very large and can be seen from any part of the power station, which is certainly very desirable. When alternators are thrown in parallel, a man is almost always stationed at the throttle of the engine or at the controller of the water gate, so it is very desirable to have an instrument which he can see, so as to adjust his admission of power as the machines accelerate or retard, and this function is very satisfactorily met by the instrument which Mr. Lincoln has described.

Mr. Gano S. Dunn:—President Steinmetz has asked me to contribute something to this discussion, which I am loath to do, because my principal interest in it is not on the part of meters, but is developed by the remarks of Mr. Barstow in regard to the wattless or borrowed current, in central stations. My contact with such work has been in comparing the starting currents of alternating current motors with those of direct current motors, and as some of you know, my work is with the direct current altogether. It is a fact, especially where motors are called upon for more than their normal torques, that the borrowed currents are very great. I have been unable to harmonize the amount of current that the manufacturers claim will be taken in induction motors with the amount of current that it is actually reported they do take. For instance, certain motors with which I am familiar are claimed to start with about 4.4 times their normal running current, whereas the testimony of the station men that have these motors running on their circuits is that they take nearly double this amount; and practically the evidence that I have is that the induction motor starting currents are normally very excessive. As Mr. Barstow pointed out, not only does this make a service delivered by the station that is not paid for, but it introduces other difficulties, such as bad regulation, affecting lights, neighboring motors, etc., which are very serious, and I believe that it is true to-day that these large starting currents and the large wattless currents necessary to secure a large torque are among the principal things that are impeding the development of induction motors, and any improvement that would remove these impediments would see the induction motor far ahead of where it is now.

MR. RALPH D. MERSHON:—I cannot agree that it is necessary to have an excessive starting current in the induction motor. There is no reason why the excess of current over that of the direct current motor should be more than 10 per cent., if that, and there is no reason that I see why there should be any limit, within reason, to the starting torque of the induction motor. The motor having the objectionable qualities mentioned by the gentlemen who have spoken, is the motor with the closed circuit secondary. It is true such a motor does start with a large current, the amount of current depending upon the torque required, but if a motor of that sort is installed, it is installed because of the desire for the simplicity and the reliability that such a motor gives, and part of the price you have to pay for that is a larger starting current than would be taken by a direct current motor. If on the other hand there be installed a motor without the closed coil secondary and with slip rings enabling one to introduce into the secondary at starting a resistance, then the motor may be started in a manner and with a result very similar to that of a direct current motor.

The regulation of the system when a motor is started with resistance in its secondary, should be just about as good as with the direct current motor. A motor starting under those conditions will have, it is true, a power factor somewhat less than unity, but the difference is too small to be of consequence. As regards the regulation of the supply system after the motor has begun to run and carry load, I think you will find—in fact I know you will find—that the variation in voltage will be less as the load on the motor varies than it will be with the direct current motor.

It does not seem to me that you can charge for wattless current. The customer is paying for power and ought to be charged only for power. The difference which the wattless current will make as regards the capacity of your generating station is not so great as it is ordinarily thought to be. The motor load is generally a comparatively small proportion of the total output of the station at the time when the lighting load is heavy. At the time when the lighting load is light the motor load is even then, in general, considerably less than the total output of which the station can take care. When the lighting load is heavy, the lighting load itself brings the power factor of the system up to a very considerable figure, so that the sacrifice as far as capacity is concerned is comparatively small. But suppose you make an objection to that sacrifice in capacity, small as it may be—what are you going to do about it? Are you going to supply power by direct instead of alternating current? If you undertake this, under most conditions, the extra apparatus, extra care, extra operating expense and extra maintenance, to supply direct current power, will more than overbalance the interest on the investment for the increased capacity which would be required in your generating station by reason of a power factor somewhat less than unity.

MR. C. F. SCOTT:—In the present somewhat random discuss on several statements have been made concerning the induction motor. The "squirrel cage" form of secondary winding has been suggested as the cause of more or less of the troubles which come to the central station man. It has been asserted that a certain motor requires between eight and nine times the full load current for starting. One would hardly be justified in concluding from this statement that all induction motors under all conditions require a starting current in accordance with the figures reported. Was the motor referred to one which can properly be taken as a type or representative of all induction motors? Was it operated under normal and proper conditions? Were the starting devices properly used? What was the torque actually developed? The statement standing by itself gives no more valuable information than would the assertion that a direct current motor may be started in such a way as to take an initial current ten or twenty times its full load current.

In the preceding discussion it has been implied that the starting current of an induction motor considerably augments the amount of power required and the resulting meter readings. It should be evident, however, that an ordinary constant speed motor requires but a few seconds for starting, so that the total energy taken during a day's run will be scarcely affected whether the motor requires its full load current or ten times that current for a few seconds in starting.

The general term "induction motor" as was pointed out by the last speaker, covers the two varieties of motor, the one with a short-circuited or a "squirrel cage" winding and the other with an adjustable secondary resistance, the latter permitting the lower starting current, but having the disadvantage of being more complicated in construction. What the last speaker pointed out is worthy of being emphasized, that the mere point of starting current is not the whole criterion by which a motor is to be judged. Its construction, its simplicity in operation, its non-liability to get into trouble, its behavior under extreme and emergency conditions—all these things are points that should be taken into consideration in the broad study of the performance of a motor.

With respect to the expense of running motors it may be noted that the items of cost of direct current motors and of alternating motors are not of the same kind. If we grant that the induction motor on account of its magnetizing current or other reasons may on the whole require a greater first investment, yet on the other hand the cost of maintenance of commutator and brushes of the direct current motor, the greater expense incurred for maintenance and for repairs, necessitated by wear or accident will in general far more than offset any additional first investment which might be required for installing induction motors.

MR. DUNN:—The topics that we are discussing are meters and power factor indicators, and when I made my first remarks I announced that it was with hesitation, because they tended toward the subject of the relative values of direct and alternating current motors. Mr. Mershon, and also Mr. Scott, have made a number of statements, that I feel compelled to deny, but I do not feel that this is the proper time or place to discuss them, and therefore I wish to remark that I do not accept their conclusions, and file an application to discuss the subject at some other time with those gentlemen, if I may have the privilege.

THE PRESIDENT:—I do not think we are so far out of the way in discussing somewhat in connection with to-day's topics the question as to whether the induction motor gives rise to excessive currents or not, because when discussing power factor indicators the first and most important question to determine is, whether such instruments are necessary at all. If the power factor is sufficiently close to unity, so that it does not need to be considered, and if the excessive wattless currents are harmless, if existing only for a short time, then we do not need a power factor meter. So it is quite desirable to consider, whether conditions exist in alternating current systems which should be guarded against by a power factor meter; and it seems there is a disagreement of opinion in this matter. According to Mr. Mershon and Mr. Scott, there is no need of a power factor meter, because the power factor is usually high enough, and where it is not high enough, it is low for a short time only, and it would do no harm; and even if it is always low, the regulation of the system is good enough. Mr. Dunn, however, contends that the induction motor is vicious in the current it takes; and you have to put in some instrument to make the customer pay for the excessive current. Personally I am really somewhat inclined to the opinion of Mr. Mershon, that the induction motor can be built so that it will require no excessive current in starting, although I would enlarge upon Mr. Mershon's statement by saying that that does not necessarily imply sliding rings, or collector rings, but the starting rheostat can be carried by the revolving motor armature, together with its operating switch, which may either be automatic (centrifugal) or hand control.

The characteristics of the induction motor form one of the topics of to-morrow's program, and since we have some time to spare to-day, but will probably be crowded for time to-morrow, I see no objection to anticipate this part of to-morrow's program. Therefore, I think it quite desirable that Mr. Dunn should make his statement opposing the statements preceding his last remarks. While, as stated, the induction motor may be made so as not to require excessive current in starting, that is, to start with not more than full load current, when giving full load starting torque, this performance is not up to the continuous current motor, where a heavy starting torque is required. Under conditions where

good regulation of the system is needed, with frequent starting, as in our larger cities for elevator service, continuous current motors have been built for years, which give a starting torque exceeding full load torque, while consuming less than full load current, and no induction motor has ever done that, nor ever will.

I will call on Mr. Dunn to supplement his statement.

MR. DUNN:—There is a tendency to force an antagonism between direct current and induction motors which I wish to deprecate. But the statement often made that for all purposes induction motors are more satisfactory than direct current motors I most formally and emphatically challenge. I yield to the induction motors the credit for their splendid properties, their simplicity and the fact that where our great systems of to-day are becoming systems of high-tension transmission and low-tension distribution, they often offer advantages that direct current motors do not. But the question of starting current is only one of the objections to induction motors, there are a number of others. If the statement I have mentioned could be maintained, it would mean that induction motors are as subject to speed control, that they are as efficient at all loads and that they are as capable of exerting torque as are direct current motors, also that their maintenance is so much lower that the saving in their operation in the long run more than pays for their greater first cost. Now, as I look back over these claims there is not one of them that I am not willing to combat.

This is the declaration that the President desired me to make.

MR. MERSHON:—The gentleman has said some things implying that a claim had been made to a greater suitability of the induction motor for all kinds of work. I do not think a statement of that sort has been made thus far. There are unquestionably conditions in the present state of the art under which a series direct current motor may be used more advantageously than the induction motor. I do not at this time recall any condition under which I would admit that the direct current shunt motor can meet the requirements better than the induction motor, unless it may be one where the voltage of the generator is controlled in order to control the speed of the motor.

As regards some of the special uses where the series motor gives better results, such as elevator work, as referred to by our President, under some conditions the series motor is very greatly better, but even in the case cited I will not agree with his statement in its full strength. I should want to dilute it a little bit. In shop equipment, there are some conditions where direct current is more advantageously used than the alternating; and in that line of work I might add an exception to that I mentioned a while ago where the direct current shunt motor might be more advantageously used than the induction motor. It is that where a number of voltages are made available so that the shunt motor may be operated at any one of a number of speeds but at any

one speed will act as a constant speed motor. The cases where the equipment necessary for such service is justified are, I think, few.

As regards the question of first cost, the induction motor is more expensive than the direct current motor. With regard to the question of maintenance, durability, care of operation, I will put the induction motor before the constant current shunt motor every time, no matter what the service is. I have seen them operate and continue to do so under the most extreme conditions, receiving abuse under which the direct current motor could not exist. I have seen them in use in stamp mills, with absolutely no protection, with quartz dust falling in every direction, quartz dust getting into bearings and windings, and, by the way, the motors of the case of which I am speaking, the worst case that I know of, were motors with collector rings, and the collector rings were being continually cut by the quartz dust. These motors were on foundations which were not worthy of the name, and overloaded to the point where it would seem as though they must burn out every minute. I do not think there is any question as to which motor is the more durable and which will give the less trouble and cost the less for maintenance.

MR. DUNN:—We seem to be taking specific cases, which are easier to discuss. I understood Mr. Mershon to say that excepting the conditions of speed control obtained by varying the voltage of the generator, he knew of no one point in which the induction motor was not superior to the shunt wound direct current motor. Let us assume, for the moment, that this control is not an important feature and pass to the other points. I have been going over in my mind some data of a certain size of direct current motor on which I personally made some tests with induction motor comparisons in view, and I do not see how, if Mr. Mershon and I accept the same data, his statement can stand. For instance, in regard to the starting torque. The starting torque claimed by one of our manufacturing companies for its induction motor of the same size as the direct current motor that I have tested, is 2.2 times the normal torque. The corresponding direct current shunt motor I started with 6.4 times its normal torque. The starting current for this same induction motor is claimed to be 4.4 times the normal running current. The direct current shunt motor required for the same torque only 2.4 times normal running current. The efficiency of the direct current motor was higher at full load than that of the induction motor, and at overload vastly higher. The direct current motor hung on to its work and did not stall until it was loaded to 6.4 times normal torque. The induction motor fell out and gave up the fight at about 2.7 times normal torque. [See page 880, discussion communicated after adjournment.]

With regard to the motors that worked so well in quartz dust, which Mr. Mershon cited as a remarkable fact. I have had

direct current motors, a whole plant of them, working for a long time, in graphite dust, and some of them in places where the graphite settled 1/32 of an inch over night, and this plant is giving entire satisfaction. The only trouble that has been experienced has been, not at the commutator, but at the rocker arms, and has been due to slightly faulty insulation where the brush studs went through; an easily corrected trouble. Now, I am of the opinion that when it comes to a question of dust, the direct current motor is ahead of the induction motor on account of its larger air gap. I have known cases where induction motors have stalled from running in dusty places because of their small air-gaps filling up with dust and causing them to jam, and, contrary to the general opinion, it is impossible completely to encase the induction motor, because the sacrifice of capacity is then too great.

One would be inclined to think that induction motors were free from troubles, but they have troubles of their own that the direct current motors do not experience.

With regard to the question of maintenance, it is very difficult to get accurate figures, because in this country the plants in which motors are installed are usually so anxious to get their motors running and turn out their work that they have no systematic means of keeping account of the maintenance expenses. But I would say that most of the figures given for the maintenance of direct current motors are taken from records that have been kept for a number of years past, and they apply to the older and imperfect types of the direct motors and not by any means to the perfected modern direct current motors that you would buy if you bought them to-day. The direct current motor has been progressing without attracting attention, and it has been progressing in many ways as rapidly as the induction motor. To-day the commutator troubles of the direct current motors of the most advanced design are reduced to only a fraction of what they were a few years ago. If you are comparing induction motors with direct current motors, compare to-day's motors of each type, and do not compare direct current motors of a few years ago with induction motors of to-day.

Now, with regard to the feature Mr. Mershon excepted, namely, the controllability of speed—this is not a small matter nor one that will permit being excepted. It is a vastly important matter, and as far as the equipment of machine-shops goes, I consider it a deciding matter, because machine shops, wherever you find them, require from one-third to one half of their work to be of controllable speed character; and if you can offer a motor which, without sacrificing efficiency or stability of speed, will give you a speed controllable at will from the very lowest values to the very highest, you there offer an advantage enough to offset the advantages claimed for the induction motors; and to cap the climax, the direct current systems are considerably less expensive because of

the smaller capacities required in the motors and because you are not at the necessity of providing for the borrowed current which you have to provide for in the wiring, generators, instruments, etc., when you put in an alternating plant.

Mr. W. S. Barstow:—When I started this discussion I did not realize how it was going to end. From the central station point of view I think that the "direct alternating" current motors are the only motors to use. There was one matter I mentioned before that I might perhaps speak of a little further so as to avoid any misunderstanding. I mentioned the fact that from the central station point of view it might be a good thing if there was some way of the station receiving returns for this borrowed energy. I meant that more in the form of a penalty. With direct current motors the station has no trouble, because the direct current motor rapidly reached a permanent development and has been in use for many years. The alternating current motor is more or less in a transitory state. We find in central stations that many of the customers, or would-be customers, buy motors second-hand on account of the higher cost of the new alternating current motor over that of the direct current motor. When they buy these motors from the jobber it is almost impossible for the central station to carry out faithfully the specifications for connecting motors to the system. The customer will come to the station and inform you that he has already bought a motor. You investigate and find out that it is an old style induction motor which takes a large amount of starting current. You have got to take either one of two positions. You have either to refuse to connect the motor to the system, although he has already bought it, or you have got to connect it and make some special excuse for so doing. That is the commercial difficulty. If a customer notifies the company that he is about to purchase a motor, that difficulty is easily overcome, as almost all central stations these days have specifications for the connection of different devices to the system. When I mentioned the fact that it would be a good plan to secure some return for the wattless current, I had it in mind as a penalty for the customer who bought motors of a cheap or antique type and who still persisted in trying to force the station to waive its requirements and connect him to the system. If all customers could be given to understand that even if they were connected they could save money by buying a modern motor in the first place, that difficulty would be removed to a very large extent. But where they can appreciate no difference, except as it aids the central station, they often absolutely refuse to make any change; and, as I say, the station has the choice of violating their own requirements or of flatly refusing to connect the customer.

Mr. Mershon:—In regard to the question of absolute cost in the installation of the direct or the alternating current motor, I do not want to go into that subject at all. I will say, however,

that in a great many cases, I think in most cases, the advantage to be gained by the use of the alternating current motor justifies paying some more for it. I won't say how much.

Mr. Dunn spoke of two motors which he compared, one presumably a commercial alternating current motor; another presumably a direct current shunt motor. Whether it was a standard one or not, I do not know. What was the temperature rating of that motor, Mr. Dunn?

MR. DUNN:—The other motor was a standard motor taken directly out of the storeroom, with no change or modification made whatever.

MR. MERSHON:—What was the temperature rating?

MR. DUNN:—Forty degrees, centigrade rise, under continuous load.

MR. MERSHON:—As regards the question of efficiency; in this particular case that Mr. Dunn cites, the efficiency was greater in the case of the direct current motor. That is not very surprising. If you compare the direct current motor lists of different manufacturers, one of whom makes presumably just as good a motor as the other, you will find that the efficiencies of one list will be the higher for some sizes of motors, and the lower for the other sizes. This will be true also with the alternating current motors, and it may have been in this case that Mr. Dunn unwittingly compared a comparatively high efficiency direct current motor with a comparatively low efficiency alternating current motor.

The motor to which Mr. Dunn referred was evidently a motor with a closed coil secondary, a "squirrel cage" winding. For the service contemplated for this motor in which it was to give six times its full load torque, the motor was not the right one. It should have been a motor with rheostatic control. As regards the question of six times full load torque, where such is necessary —it is not necessary in many cases,—but where such is necessary, it can be obtained with the alternating current motor. The accessory apparatus for obtaining it would be more or less special, it is true, but I think most of you will agree that the requirement of six times full load torque in a constant speed direct current motor is a more or less special condition, and that it would require accessory apparatus which would be more or less special. You certainly would not use the same mechanism in the case of a motor which was to start with six times its full load torque, as you would with a motor which was to start with full load torque, or $1\frac{1}{4}$ times full load torque.

As regards the specific instance which I cited of an induction motor running in a stamp mill and subjected to quartz dust, it was stated that it ran under conditions under which a direct current motor would have fallen down. This statement involves, of course, the element of personal opinion, but, as a matter of fact, the conditions under which those induction motors were running, with no attendance—for they had none, absolutely none

—were such as no direct current motor could have withstood. As far as the graphite factory is concerned, I do not know the quality of the graphite, but it seems to me that good graphite would cause no injury to an induction motor, on the contrary it might aid in the matter of lubrication, whereas the quartz mill would not be a very nice place for any kind of a motor. I do not think there can be any question about it, that the chances for trouble in the case of a sliding contact, where you have simply a slip ring, are very much less than in the case of a commutator where the contact is continually changing, and by reason of which change there is continual chance of trouble.

THE PRESIDENT:—The discussion has drifted toward the relative merits of the continuous and the alternating current motor, and both sides have been very ably represented; yet it seems to me that neither of the two sides has been able to prove that either type of motor is universally superior, but that both have their good features, in some instances one being preferable, and in some instances the other; for instance, when running in an oil refinery or a powder mill, use the induction motor, and when running a railway, as a rule use the continuous current series motor. Between these two extremes there is an enormous range of conditions where each motor can find its place.

But there is one point which Mr. Barstow brought out, that these specifications should be made, to guard against the use of any inferior motor, and to secure a motor suitable to the conditions. The ordinary motor is very suitable to drive a mill or factory, but in a close regulating alternating system it is not always desirable. Specifications regarding motors have been made in continuous current systems—and I could tell a tale about them, at the time when I was connected with electric elevator motor design, and we had to develop a constant speed motor giving more than full load starting torque with less than full load current. We produced this by adding a powerful series field, which took the part of the starting rheostat, and in starting was gradually and in sections cut out. But I am sorry to say that in the alternating current systems such specifications have not always been maintained, and alternating current motors have been installed of a type which should not be installed, and it is for that reason that a discussion such as this as to the relative merits and demerits of the two types of motor is very useful, by drawing our attention to the necessity of considering the matter, not as a thing by itself, but as a part of the system, and to be chosen to suit the remaining part of the system, and not to be chosen at random from the infinite variety of types available on the market.

There seems to me, therefore, some reason to assume that the question of power factor is important, and that power factor meters are of use and value. Thus we come back to the discussion of meters; and as Mr. Hering has given this matter quite a good deal of attention, I should like to hear from him about meters and his experience with them.

MR. HERING:—I am sorry to say that I cannot contribute anything new to the discussion of the subject of meters. I am glad to see that the value of wattless current indicators is beginning to be recognized, as I think they are very important instruments. Regulation, especially of rotary converters, and other desirable results can be obtained by a suitable wattless current indicator, more directly and with less difficulty than with only the usual instruments from the readings of which the wattless current can be obtained only by calculation.

If I may be permitted, for a moment, to go back to the other part of the discussion, however, I would like to cite a case which is of interest concerning the starting torque of induction motors. I had the pleasure last year of taking a ride on a three-phase railroad in Switzerland, the only one which is run under steam railroad conditions. The cars were all of the large steam railroad type, and there were about three or four cars to a train. I refer to the Burgdorf-Thun Railway. I rode with the motorman, reading the ammeter as he started the train, and noticed that he seemed to cut out the starting resistance of the induction motors so as to keep the starting current about double the normal and no more.[1] The ammeter seemed to be his guide in handling the controller. The train was therefore started with no more than double the normal running current, which I think is a very good result. To be sure, the train did not start so suddenly that the people were jerked off their seats and had to expend a lot of energy in keeping their places, but I think that is an advantage rather than otherwise.

MR. MAILLOUX:—I would like to state, exactly on that same point, that Mr. Arnold and I were on the same road either a day or two before or after Mr. Hering; but the motorman may not have been so careful, because I noticed that the motor did not start with quite the regularity and uniformity that Mr. Hering speaks of. The motorman did not know that we were observing an ampere-meter which was at the other end of the car and which gave all the readings; and these readings fluctuated quite considerably. My impression is that the starting current was much more than twice the running load.

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1 Since the above discussion took place I found a published statement according to which the current is even less than what I had noticed. In *Engineering* (London), November 1, 1901, p. 626 there is a communication by Brown, Boveri & Co. (who designed and constructed that road), in which the following statement occurs: "As regards the simple resistance control, this is not nearly such a bad system as some people would like to make out; it may be of interest to your readers to hear in this connection that on the Burgdorf-Thun line we start heavy trains on the level, with an acceleration as high as 1¼ feet per second per second, *without taking more current from the line than the normal current*." The italics are mine. I now recall that when I made my observations the train was ascending the gradual rise on the southern part of the line, which accounts for that larger starting current.—C. H.

I do not quite agree with Mr. Mershon as to the unfairness of charging the customer what Mr. Barstow has so aptly termed a "penalty" for the abuse of the current or because it is used under improper conditions. The fact is that a penalty system is already in use regularly in most central stations. We have negative penalties in the various forms of extra discounts which are given to customers who use current during the day time. The man who uses it only at night pays more in many cases. The man who uses more per lamp or per month also gets an extra discount, so that the man who does *not*, is really paying a penalty. It seems to me that the plant is subjected to the abuse of extra generating capacity, so to speak, by the party who puts an extra wattless power demand on the line, and it ought to be paid for just as much as the failure of the customer to raise the load factor of the station is susceptible of a penalty and is usually taxed by an extra charge. I have had some practical experience with cases showing the necessity of power factor indicators and also of a penalty for introducing excessive wattless current. One was a small plant of somewhere between 150 and 200 K. W., which for convenience, owing to the distance of distribution, used alternating current at about 2000 volts. The service was a mixed one, including lighting and power; at times mostly lighting and at other times mostly power. There was one customer who used about 75 H. P. in motors of two or three sizes, and although the motors were to be run only or mostly during the day at a time when there was very little or no lighting load, yet it would occur repeatedly that the starting of one 30 or 40 H. P. induction motor would not only stall the line but actually blow the fuses at the station. This typifies and illustrates the necessity and the equity of a penalty for an excessive wattless current. These motors were, I understand, of the very kind which are said to take the least current, owing to the fact that they have slip rings and internal resistance, or a variable armature resistance. They may have been greatly improved in the three or four years which have elapsed since; but the fact remains that oftentimes the starting of a 40 H. P. motor has thrown wattless current enough on the line to blow the fuses of a 150 or 175 K. W. unit; and this occurred so repeatedly that finally the system had to be abandoned and direct current had to be introduced instead. I have also seen many cases of installations, even on a very large scale, of plants having as much as a total of 2500 H. P., where the use of the alternating current was entirely inadmissible, although the units in service were large, the average size of motor being somewhere between 25 and 35 H. P., the reason being, simply, that they could not obtain that variation and regulation of speed which is essential in most cases where power is applied on an extensive scale in factories and for industrial purposes. There was a very interesting discussion on this very matter just about one year ago at Paris in the joint meeting of this INSTITUTE and the Institution

of Electrical Engineers of Great Britain, in which many representative men of both countries present took part. I think the conclusions drawn from that discussion were to the effect that there is no one system which is applicable to all cases, that the non-synchronous motor, or induction motor, has a sphere of utility quite its own, in which it is preferable. Of both it may be said that there are uses where cost is not the independent variable; where there are other things which are of stronger import than the cost. So that, if we are going to compare motors and are going to compare them on the score of cost, we should take cases in which cost is the independent variable. If we are going to compare them in cases where absolute safety is the prerequisite, such as in the case of a powder mill, cited by our honored President, then of course we have another condition, where cost is entirely out of the question, where safety must be had at any cost and under any circumstances, a case in which the bare possibility of a spark from a commutator is a reason for excluding, of itself, all thought of anything but the induction motor. Those may be said to be cases which are entirely *sui generis;* as such they call for specific treatment. I am entirely disinterested; I have made interesting and useful installations with both systems. I love to apply each system to that purpose for which it is best suited, as I think every conscientious engineer does and should; but I do not like to see a spirit of partisanship induce one to compare things which cannot be compared. It is hardly fair to either system to undertake to establish a comparison between two things under conditions under which they cannot be compared any more than stones can be compared with eggs.

MR. MERSHON:—I want, Mr. President, to endorse the last remarks of Mr. Mailloux. One reason why I have taken up this matter is, that discussions before this INSTITUTE and elsewhere have left the impression with many that the alternating motor had no right to live and that there was no use for it; that about the only place for it was the junk heap, and that the direct current motor was the only thing to be used. That is one reason, as I say, why I have taken up the question of the alternating current motor. Beside that, I think it is one of the most beautiful pieces of mechanism we know of, from every standpoint. I will admit, as I did a while ago, that there are some uses for which the direct current motor, and especially the series motor, is better adapted than the alternating motor, and in those fields the alternating current motor has not very much chance; but there is a common ground, and there is a ground furthermore, that is not common to both, but which is pre-eminently the field of the alternating current motor. Throughout this discussion I have had in my mind generally the idea of the constant speed motor, any motor which normally operates at constant speed. It is better to put this limit on such a discussion as this one, because it simplifies matters since entering into the variable speed field

means more or less complication, not only in engineering but also in discussion, no matter which system you take up.

MR. SCOTT:—My good friend, Mr. Dunn, made the statement that what he was contending against was the proposition that for all cases, for universal application everywhere, the alternating current motor was the best, and that the direct current motor had no place where it was to be chosen against the alternating current motor, implying, as I took it from his language, whether intended or not, that I had taken the position that the alternating current motor was the thing to use everywhere. I very readily and heartily agree with Mr. Dunn in the position, which I have always held, that the direct current motor has its place and the alternating current motor its place. As has just been stated, each has its own field, its own characteristics, and ought to be selected for its own work. But what is its own work? The two extremes are well defined, but it is this middle ground, this dividing line, on which we are somewhat at variance and on which the good judgment of the engineer—not alone the manufacturing engineer, as his judgment may not be good—but of the consulting engineer, of the general electrician, must come in in deciding the relative merits of these motors. As I recall, one of the statements made was that wherever an induction motor could be used, a shunt motor could be used with equal or better success. Let us for just a moment make a common sense comparison between the two motors themselves. In the direct current motor, one of the most prominent elements is the field winding, made up of large coils of fine wire, which must be well insulated to prevent injury from "field discharge" and which are sometimes liable to overheat. The alternating motor has no field winding at all. Another prominent thing about the direct current motor is the brush holder, "a little thing which could be easily corrected if it did not get out of order," and brushes do wear. The alternating current motor has no brushes and no brush holder. The direct current motor has a commutator, the induction motor has none. The direct current motor has an armature winding, consisting of a large number of coils, properly connected. The alternating current motor has a primary winding for receiving current which corresponds closely to the armature winding of the direct current motor. Both have those windings, but one is on a revolving armature frequently held by band wires and connected at a hundred points to the commutator. The other is stationary, in an outer shell, with only a few connections to the outside line. I confess that my electrical experience has been such that to my mind there is a difference between these two constructions, and that the direct current motor is by no means the equal of the alternating current motor in any of these respects.

Reliable general data as to cost of maintenance is difficult to secure. As has been stated, records of maintenance are fairly well kept with direct current motors. They have been longer in

use and records have come to be a matter of form. With regard to the alternating current motor, records of maintenance are perhaps not so available. In some cases there is no record of cost of maintenance, as has been stated by engineers who have been running the motors for quite a while, and who point with pride to that fact.

Complaint has been made against the alternating system that the generators must be larger in order to accommodate the extra current, the "wattless" current. Sometimes the same machine is used both for direct current and alternating current, the commutator being at one end and collector rings at the other. Therefore, to make an alternator out of a direct current generator, you may simply make connections from the winding to collector rings and leave off the commutator, which is one of the very large elements of cost in the direct current generator. The saving thus effected can be applied in such a way as to give an increased output from the alternator and thus make it able to deliver the exciting current which is needed by the motors.

Referring again to the cost of power; in a manufacturing establishment or a mill, the total cost of power, including fuel, interest and maintenance, often does not exceed a few per cent. of the total cost of manufacture. A very large increase therefore could probably be made in the cost of the power plant, if greater simplicity and greater reliability can be obtained in that way.

In about all that has been said in this discussion this morning, it might be inferred that the alternating current motor was merely a possibility of the future. The alternating current does not, however, lie wholly in the future. As a matter of fact such motors are in use by the thousands. Those with "squirrel cage" secondary windings constitute the principal output of alternating motors of the Westinghouse company, and the number of these motors now in use runs up into very large figures—I have not the exact statistics in mind—but if I remember correctly, there are, in addition to many other uses, something like 100 industrial plants which are running with induction motors.

THE PRESIDENT:—Much more than that.

MR. SCOTT:—Mr. Steinmetz, with reference to another company, adds to the number. The motor has established its place, and it is a notable feature that where alternating current motors have been used they are in such high favor that when extensions are being made or other plants of the same operating company are to be installed, the choice is quite sure to be in favor of alternating current motors.

MR. F. S. HOLMES:—This discussion reminds me of an experience of some of our number at Alt Nuernberg last evening at supper. They were not apparently used to American methods, and I heard one of them say that $13 for that supper was a "darling." Now, there is a wish among men to get an equivalent for what they spend. We have been told by the people

representing the induction motor that it has no commutator and no field winding. In fact, there is very little to this motor except price. For this reason, gentlemen, the manufacturing contingent of this country declines to take induction motors in isolated plants, where current is not distributed long distances. In Europe the induction motor is cheaper than the A. C. motor. For the present condition of affairs in America we must thank the U. S. patent office and combinations.

There are two or three objections to alternating current stuff beside price. I speak now not of long-distance transmission but of local work in factories. A hanger must be limited in drop because its ceiling has a limited height. The speed of induction motors has been high. Power should be applied directly, and not by a counter-shaft to a main line. It has been very difficult to find motors of the A. C. type which could be hooked up directly to shafting without very long hangers. That is an objection that is disappearing as we get the frequencies reduced.

Again, if I go to a manufacturer of direct current apparatus and say, "Build me a motor to run at 353 revolutions per minute," he builds it. But when I try to get an A. C. motor which does this, what is the result? It can't be found. Alternating current motors have certain speeds, determined by the frequency and the number of poles in the motor. You cannot change these relations. Summing up, in isolated plant work where long-distance transmissions do not occur, I would say that purchasers are deterred from buying A. C. motors, first, because of price; second, because of high speeds; and, third, because of inflexibility in application.

MR. E. A. SPERRY:—I am surprised to hear the last speaker sum up in his able manner on isolated plants without adding a fourth numeral, namely, the relation between direct current and storage. This, as we know, is often the point that determines the application, the point that determines which system has to be selected; and I have been rather surprised that so important a factor has been left out of the discussion up to the present time. And, Mr. President, if I may be permitted to digress at a considerable angle from the line the discussion has taken, while I have the floor I wish again to call attention to the really new apparatus that has been presented to us at this session, namely, that of Mr. Lincoln. I have seen the apparatus in operation somewhere at the Exposition, and I hope some one will tell us where, so that others may see it. It is certainly a most interesting device. I noticed particularly the directional factor. Not only does this tell us when we are not in step, but tells us which way out of step we are, which the ordinary apparatus, of course, does not do. This to me was of interest.

PRESIDENT STEINMETZ:—Gentlemen, before giving the floor to Mr. Dunn, I might be allowed to make one statement in reply to Mr. Mershon. In his discussion he said that the statement

had been made before the INSTITUTE and elsewhere that the alternating current motor was good for nothing but the junk heap, and that this statement has gone unchallenged. Now, I really do not remember that such a statement has ever passed unchallenged, so far as the INSTITUTE is concerned, and I very much doubt that it has. I believe that is a mistake, Mr. Mershon probably referring to some other association. I shall be glad to hear from him, where and when this statement has been made. I now call upon Mr. Dunn.

MR. DUNN:—I had intended not to speak again, but Mr. Scott said one or two things to which I should like to reply. He mentioned that the induction motor had no field winding. It certainly has a field created by a winding, and I should like to ask which is better—a magnetic field which, though it may be created by a winding consisting of a number of turns of fine wire, stays still when once it is created, or a field created by a winding which has to borrow its magnetism from the circuit and restore it sixty times a second. I should prefer the still magnetism. He has said there is no commutator on the induction motor. Granted; but the induction motors, even to get them down to the price that they are now at, have to have such small air-gaps that their mechanical performance is questionable. The small air gaps cause jamming when they become filled with dust, and a slight wearing of the bearings lets the armature down on the fields, and even causes in some cases such unbalanced side pull as to bend the shafts when the motor is started.

Another trouble to which the direct motor current is not subject is vibration. The alternation of currents in the direct current motor is experienced only in the armature and not at all in the field, and it is of a very much lower frequency. The alternation of current in the induction motor causes a hum and often a vibration of the winding, which ends in rupturing and destroying the insulation. Now, with regard to maintenance, whether you use direct current motors or induction motors, you must have them regularly inspected. Any plant that puts up machinery without provision for regular inspection, gets into trouble sooner or later. I claim that the inspection required for direct current motors and the inspection required for induction motors is so nearly similar that the man who goes around to see that the oil is in the bearings; that the motors are clean; that the starting devices have not burned their tips, and that the belts are in order; that man can attend to an induction motor plant or a direct motor plant with very little difference in his time.

I did not mean that Mr. Scott said that induction motors were the best for all purposes, but such is the statement that many men selling induction motors make, and the statement that I have had to meet when I have been arguing the merits of direct current motors. I ventured to bring it forth in this discussion

simply to give me a ground from which to talk. I would not risk my reputation by saying that direct current motors are the things to use everywhere; but what I do contend for, defend and believe in, is that for isolated plants, for work where you need controllability of speed, for work where you need large torques, there the direct current motor is greatly superior to the induction motor, and, withal, cheaper.

Mr. Scott went into the details of generator design, with regard to the size of the generator, but I think his point is not well taken, because there are facts, such as the difference in stiffness of field required in alternating generators and other details, that do not permit of any comparison being made, and where one cannot be made, following Mr. Mailloux's advice, we ought not to attempt it.

Taking up the double systems that Mr. Scott mentioned, that is, systems where they operate both alternating and direct currents in the same plant and out of the same generators, the reason they put in such double systems is because the alternating current system is not sufficient to do the work. I am of the opinion tha simplicity above all other things is requisite in engineering, and I do not see, where you want variable speed, heavy torques, constant speed, all kinds of service together, why you can't get those perfectly at lower cost and with a great increase in simplicity of plant by putting in one simple direct current system. This, of course, refers especially to isolated plants and factory equipments. If I were designing a plant which involved bringing power from a distance I should put in induction motors, the same as Mr. Scott.

The President:—The object of our organization is to further the advance of electrical engineering, and most advance made has always been made as the result of criticism, that is, adverse criticism; and for that reason it is very desirable that we here should endeavor not only to show the advantages of the various systems of operation, but the disadvantages also; and when this discussion comes to your hands I hope you will carefully go over it and see, in the list of disadvantages of the continuous current machine, the commutator and brushes, etc, if you will find that there are still more to add to the list; and among the disadvantages of the alternating machine you will find power factors and small air-gaps, and you will add to that everything that you can still think of; and then in the future we can go over the matter and see how all these disadvantages can be remedied; because, while both types of apparatus are very perfect, we hope that in the future they will be still more so.

In connection with that, it would be desirable to hear from our European friends, and therefore I call on Mons. Boy de la Tour to give us a few words regarding European experience.

Mr. Henri Boy de la Tour:—(Translation.) I believe that it is difficult to decide either for the direct current motor or for

the polyphase non-synchronous (induction) motor. In my opinion there are numerous cases which call for the direct current, but there often exist installations where the use of the inductive motor has its advantages.

These motors have been criticised for their small air-gap and the large currents which they require in starting to produce a relatively low torque. But do not these motors present the material advantage of being, in comparison with the direct current motor, more simple, more robust, and of requiring, so to speak, no attention, and of being suitable to be put in the hands of almost any workman?

Mr. Steinmetz has said with reason that the synchronous motor could always be built so as to produce at starting the normal torque while absorbing only the normal current, but it is true also that it is possible, by means of special connections, to make a direct current motor give the normal starting torque with a current which is only from 65 to 70 per cent. of the normal running current.

The direct current motors have been very warmly defended here, and the idea has been admitted that they might, in the future, be preferred to the induction motors. One must not forget that inasmuch as nature does not produce anything but alternating currents, the laws of nature have, so to speak, been violated in the direct current motor. This thought makes me believe that the direct current machine can scarcely be the ideal definite machine, but that we find ourselves in a transitory period, and that the present induction motors, which are already excellent machines, will give place to a new alternating current motor, which will advantageously replace the two types at the present time before us. However, I repeat that in the present state of our science, the two systems both render us great services, for their different qualities enable them to complement each other happily to greatly facilitate the solution of problems which are oftentimes very difficult.

MR. HENRY W. FISHER:—From the experience of the manufacturer there may be something said on this point. I happen to be connected with the manufactories of the Standard Underground Cable Company, and in one factory we employ direct motors, and in the other factory induction, three-phase motors. Both factories have run successfully with the different types of motors but the difference is this, that every once in a while we have to take our direct current generator and our direct current motors and turn down the commutators, but in the case of the induction motors nothing whatsoever has had to be done. The induction motor generator does not have to be repaired, and the induction motor does not require any special attention as there is no commutator to be turned down. So that if I were putting up another factory I would certainly use the induction motors, because they certainly give less trouble than the direct current motors.

MR. H. G. STOTT:—Mr. President, I would like to pour a little oil on the troubled waters and say that there is a connecting link between the alternating current and the direct current motor which we seem to have forgotten, and that is, the rotary converter. With that, the direct current man can look at the direct current side, and the alternating current man can look at the statics and the collector ring end.

Another point seems to have been overlooked, and that is as to whether we are receiving current or whether we are generating current locally for short distributions. These two points make a radical difference. If you are receiving current, undoubtedly the alternating current is the thing to use; but there are two ways of utilizing this, either with the static transformers and rotary converters and the use of direct current, or simply to put in static transformers and use.

Now, there is still a third way which in many cases is advisable, and that is to put in motor generators. You can put in a motor generator at almost any voltage, provided the unit is of large enough size, say 100 H. P. providing a 2200 or 4400-volt motor, either induction or synchronous. With the synchronous motors we have the advantage of running our power factor to any amount we wish. I think that we can all agree that there are certain cases where one motor is out of the question, and others where the other is out of the question. In a large plant being put in in New York, for instance, just now, the question of operating came in with regard to a coal-handling apparatus. Of course our engineers decided that the induction motor was the proper apparatus to handle that; but when it came to equipping the cars, all agreed in favor of the direct current motor, with just the same unanimity. There was no more question in the case of the one than in the other. So I think we can all agree to differ.

There is a point raised in one of the papers I think that is very important to central station men, which has not been taken up much, and that is the question of meters. In selling current it is unquestionably unfair to the central plant to sell current at the same rate per K. W. to men who only use the power during the peak of the load, for perhaps two hours, and throw this peak on top of the other load, as to the men who use the current for perhaps twelve hours a day, or even longer, and who use the current when it does not add on to the peak load. The peak load is the all-important factor in practically all plants. Now, I would like to hear from the representatives of the manufacturing companies as to what progress has been made in the designing of meters which would differentiate, as it were, between the two kinds of customers; in other words, a two-rate meter, or some other device, which would show the amount of current used between certain hours at the maximum, and also the amount of current used between certain hours of small load. I think that this is a very important point and that we could hear with a

great deal of interest from the different representatives of the large manufacturing companies.

THE PRESIDENT:—I would like to call on Dr. Janisch of Germany to give us a few words concerning his experience on these topics.

MR. CHAS. JANISCH:—The question "Is the alternating or the direct current motor the better?" is a question which I would not like to answer without reservation. Both kinds of motors have their good qualities which enable them to operate positively and durably. Both kinds of motors have their disadvantages which make them more or less unsuitable for certain applications. For this reason, I would like to answer the question only after a careful consideration of the proposed working conditions, and would accordingly in one case give preference to the one, in the other case to the other motor. I am much pleased to coincide, in my view, with your President, and I hope with him that the present discussion will serve materially to improve either the one or the other of both kinds of motors to such extent that their preference for all applications may be incontestable, or that we may come across a new kind of motor which combines in itself all the good qualities of the two aforementioned kinds without possessing any of their disadvantages.

THE PRESIDENT:—I will call on Mr. Haskins, then, to answer any questions.

MR. HASKINS:—I think there has been but one question asked relating to my paper. In correcting the proof of my paper, I found that the compositors had substituted the word "motor" for "meter," all the way through, and it is possible that I ought to have left it there. I am hesitant whether to think that my paper has been in such full accord with your views as to call for no contradiction, or so completely in disaccord that time would not permit you to express your disapproval. I shall infer the first. Mr. Stott has asked me what progess has been made in the commercial development of a meter system contemplating a justly higher charge for energy furnished during the peak of the load than for energy furnished at other times. This problem translated into meter language, means the "two-rate meter." The General Electric Company has had a "two-rate meter" on the market for about three years. In its original form the meter had two dials. Motion from the rotating element of the meter was transmitted either to the right hand or left hand dial, according to the hour of the day, the throw-over being accomplished by a clutch controlled by a clock. It is possible with this meter to record the energy delivered during the peak period, be that what it may, on one dial, and to record on the second dial all energy consumed at other than the peak period. The clock is capable of being set to throw over at any desired time from high to low and from low to high rate. I do not think it is appropriate that I should enter into a discussion of the two-rate system

here. It is more of a commercial than a technical topic. The double-dial form of meter, which was our first two-rate device, involved the reading of two dials, and practically the preparation of two bills—somewhat of a burden. It has been superseded by a second form of two-rate meter which has but a single dial, the reduction of rate during the "valley period" of the load, being accomplished by an actual reduction of speed of the rotating element. This change is accomplished by cutting in and out resistance in series with the armature. This provides a two-rate meter which may be any desired percentage slow during the "valley period," and at the same time involves the reading of but a single dial. The discount or reduction of rate during the "valley period" is taken care of by the reduction of speed rate in the rotating element during those hours. The change in resistance is accomplished by a clock mechanism similar to that originally used with the two-dial meter. This meter is undoubtedly preferable for two-rate purposes, and it is my candid personal belief that some day it will come into very wide use.

MR. W. HAND BROWNE:—I will not venture, Mr. President, into the discussion of the relative merits of induction and direct current motors. The question of charging for the wattless current I would also prefer to leave to the operating engineers. It was stated that a great deal of trouble had been experienced in the use of older and poorer induction motors. Would not a power factor indicator at once condemn such a motor?

[Adjourned.]

[COMMUNICATED AFTER ADJOURNMENT, BY GANO S. DUNN, see page 864.]

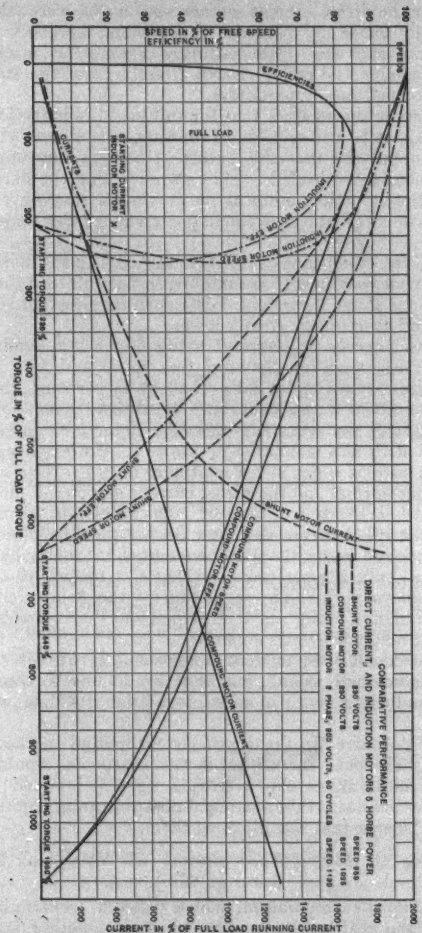
In the discussion of the relative performance of direct current and induction motors into which channel the discussion of Mr. Caryl D. Haskins' paper on meters at the Buffalo convention, turned, I referred to certain tests I had made and gave extracts from them, and upon the suggestion of one of the speakers I now submit these tests as a part of the discussion communicated after adjournment.

The tests are plotted in three sets of curves, all on one sheet shown herewith.

The first set gives the speed characteristics of the direct current shunt motor, direct current compound motor and alternating current induction motor.

The second set gives the efficiencies, and the third gives the running currents for these same motors. The three sets are distinguished by the character of their lining, which is explained upon the sheet. All of the curves are plotted with torque for the independent variable.

To secure comparative results, the scales have been written in percentages of the full load values of each quantity involved.



The data from which the curves for the induction motors were made, were taken from the publications of one of the prominent companies building such machines. The data from which the

curves for the direct current motors were made, were taken from tests made under my personal supervision, especially for this comparison, and were from ordinary commercial machines of standard commercial rating, drawn directly from the storehouse and unmodified in any particular.

The current curves show that for full load the induction motor requires about 10 per cent. more running current than the direct current motor, and that this excess of current increases as the motors become overloaded. They also show that the starting current for the induction motor at its maximum starting torque is nearly twice as great as the starting current for the same torque in the direct current motor.

The curves of efficiency show that at partial loads there is little difference between any of the motors, but at full load the induction motor is about 3 per cent. lower than its direct current competitors and at overload greatly lower.

The speed curves originating in the upper left hand corner, show that in regulation between free speed and full load the direct current shunt motor falls off about 4½ per cent., the induction motor about 6 per cent. and the direct current compound motor about 7½ per cent., and that the induction motor breaks down and stalls at a maximum torque of 2.7 times normal, while the direct current shunt motor continues until it exerts a torque of 6.4 times normal and the direct current compound motor continues until it exerts a torque of 10.8 times normal before it stalls. The speed curves also show that at the breakdown point of the induction motor the direct current shunt motor has fallen off in speed only 13½ per cent. and that at a torque of about 80 per cent. above normal the regulation of the compound motor and the induction motor are about equal and that beyond this the compound motor is greatly superior.

A series wound direct current motor would give greater torques than the compound wound, but as it would not be comparable with the induction motor in speed regulation, its data were not included.

Sparking occurred in the direct current motors in the middle region of their speed curves, but it was not such as would injure the commutator unless the overloads were maintained; and at the severest overloads the sparking almost disappeared, on account of the low speeds that accompanied them.

[Communicated After Adjournment by Mr. Carl Hering. See page 869.]

Mr. Mailloux's observation, which differed from mine, does not affect the real point at issue, which is, whether it *can* be done, and not whether it *was* done, under the particular conditions of load, grade, motorman, etc., under which he made his observation. If it can be done once it can be done again, although it may not always be done, especially when power is as cheap as it is on that line.

A paper read at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 22, 1901. President Steinmetz in the Chair.

THE INDUCTION MOTOR AND THE ROTARY CONVERTER AND THEIR RELATION TO THE TRANSMISSION SYSTEM.

BY CHAS. F. SCOTT.

Two important functions of an alternating current transmission system are the production of mechanical power and the furnishing of direct current.

The induction motor and the rotary converter have become the usual means of transforming energy into these forms. The wide extent to which they are now used is a notable feature of recent electrical progress. An examination of their behavior in service, especially in connection with other apparatus which might be used for the same purposes, will indicate the particular characteristics which have made them so successful. Occasion will be taken also to note some of the important inter-relations between the various kinds of receiving apparatus and the transmission circuit and the generators by which they are supplied with current.

I.—The Induction Motor.

Power may be produced by the synchronous motor or by the induction motor. A comparison between the two motors may be made by placing in parallel columns their respective characteristics in services, *i. e.*, those which concern the operation rather than the design. An induction motor with a secondary of the "squirrel cage" type, started by applying a low E. M. F. to the primary, is taken for comparison—the description will require modification in some particulars if the secondary circuit is provided with adjustable resistance. These are of minor importance and do not affect the general comparison.

SYNCHRONOUS MOTOR.	INDUCTION MOTOR.
AUXILIARY APPARATUS.	
1. A starting motor; or, if self-starting, some form of resistance or transformer for reducing the voltage.	1. A two-way main switch with auto transformers giving a low E. M. F. for starting. This may be located at any distance from the motor.
2. An exciter, driven by the motor or otherwise, with circuits to switchboard and motor.	2. No exciter is required.
3. Rheostats for exciter and motor.	3. No field rheostats are required.
4. Instruments for indicating when field current is properly adjusted.	4. No instruments are required.
5. Main switch and exciter switches.	5. No exciter switches are required.
6. A friction clutch is required in many cases.	6. No friction clutch is required, as the motor starts its load.
CONSTRUCTION.	
1. Armature winding.	1. Primary winding.
2. Field winding with many turns. Liable to accident from "field discharge" if exciting current is suddenly broken; or from high E. M. F. by induction from the armature if the field circuit is open.	2. Secondary, short-circuited.
3. Collector rings and brushes.	3. No moving contacts on "squirrel cage" secondary.
STARTING—NORMAL.	
1. Motor is brought up to speed without load; if starting motor is used, the main motor must be brought to proper speed and "synchronized"; if self-starting, the starting devices must be cut out of circuit at proper time.	1. Throw switch to starting and then to running position.
2. Exciter is made ready for delivering proper current and the motor field must be excited, adjustments being made by rheostats until instruments give proper indication.	2. There is no exciter. (The motor is magnetized by lagging current from the generator.)
3. Load is thrown on by friction clutch or other means.	3. The motor starts its own load.

Synchronous Motor.	Induction Motor.
STARTING—ABNORMAL.	
1. If the several operations in starting be performed improperly or in wrong order injury may result. If a starting motor is used the synchronizing may be attempted at an improper speed or phase; if the motor is self-starting and it is connected to the circuit without the starting devices a large current will flow which may induce a high E. M. F. in the field circuit; if the field circuit be open a high E. M. F. may be induced in it at other times also.	1. The only possible error is in starting with the switch in the running or full voltage position, which simply causes the motor to exert a greater torque and consume a greater current than is necessary.
2. If a load having inertia be applied by closing the friction clutch too quickly the motor may be overloaded and stopped.	2. The motor starts its own load and requires no friction clutch.
3. If motor stops owing to failure of current supply, it is not self-starting when the current returns. An attendant is always required for starting.	3. The motor will stop if the current is cut off at the power house and then start again when the current is supplied to the circuit.
STARTING AND MAXIMUM RUNNING TORQUE.	
1. The starting torque of the self-starting motor is very small and an excessive current is required for developing it. The motor starts as an induction motor, but inefficiently, as the designs which is best for synchronous running, is not good for starting.	1. The starting torque is adjustable and may be several times full load torque.
2. The maximum torque is several times the full load torque, and occurs at synchronous speed; below this speed the torque is very small: any condition which momentarily lowers the speed causes the motor to stop.	2. The maximum torque is usually greater than that of the synchronous motor, but it occurs at a reduced speed and there is a large torque at lower speeds.

Synchronous Motor.	Induction Motor.
SPEED.	
1. The motor has a single definite speed; at other speeds its torque is very small and the current is very large.	1. The motor may be designed for a practically constant speed, with large torque at lower speeds; or for several definite speeds by changing the number of poles; or for variable speed work; such as is required for cranes, elevators, hoists and the like.
CURRENT.	
1. If there is useful starting torque the current required for producing it is very great.	1. The starting current may be made proportional to the torque, and is $1\frac{1}{4}$ to $2\frac{1}{4}$ times that required for the same torque at high speed.
2. The running current depends upon the wave form. If the wave form of the motor and of the circuit differs, a corrective current will follow, which cannot be eliminated by adjustment of field excitation.	2. The running current is practically independent of the difference in wave form, as it has no wave form of its own.
3. The running current depends upon uniformity of alternations of the current, *i. e.*, upon the uniformity of the speed of the generator and other synchronous motors. The motors attempt to follow the generator speed exactly. If the latter pulsates, the motors pulsate also; they vibrate about a mean position, "hunting" or "pumping." One motor pumping incites others. The current is increased even though the conditions may still be operative.	3. The current is practically independent of fluctuations in generator speed, as there is a slip between the synchronous and the actual speed of the motor.
4. The running current depends upon the relation between the field current (which is adjusted by the attendant) and the E. M. F. of the circuit. The main current may be made leading or lagging or theoretically it may be neither. The E. M. F. of the circuit is an element which is under the partial control of the attendants at every motor as well as at the generator station.	4. The current is not subject to any adjustments which the motor attendant can make, nor is the E. M. F. of the circuit in any way under his control.

Synchronous Motor.	Induction Motor.
POWER FACTOR.	
1. As the power factor is the relation between actual current and energy-current, it is dependent upon wave form, hunting and field current. Under favorable conditions the motor may have a high power factor; under many actual conditions it may not; under some conditions the highest attainable power factor is less than that of the induction motor.	1. The power factor varies with load, but is definite and is practically independent of wave form and hunting.
2. The current may be lagging or leading, depending upon the motor field strength.	2. The current to the motor is always a lagging current.
REACTION UPON GENERATOR AND CIRCUIT.	
1. The motor impresses its own wave form on the circuit.	1. The motor has no wave form to impress upon the circuit; its tendency is to smooth out irregularities in a wave which is not a sine wave.
2. A motor may augment the fluctuations in generator speed by the oscillation of its own armature. One motor may increase the disturbance in the circuit so as to interfere with other motors which would not have been seriously affected.	2. The motor has a damping action upon fluctuations in frequency; in some cases a synchronous motor which hunts may run smoothly when an induction motor is connected to the same circuit.
3. As the current may be either lagging or leading, the drop in E. M. F. in the generator and between generator and motor may be either more or less than that which could be caused by a non-inductive load or by an induction motor.	3. The drop in the E. M. F. is always greater than would be caused by non-inductive load.
4. If a short-circuit occurs in the transmission system the motor acts as a generator, which thereby greatly increases the current and the intensity of the short-circuit.	4. The motor does not generate current when there is a short circuit.

SYNCHRONOUS MOTOR.	INDUCTION MOTOR.
REACTION UPON GENERATOR AND CIRCUIT.—Continued.	
5. If the circuit is opened, either by a switch, a circuit breaker, a fuse or the breaking of the line, the motor speed falls, its E. M. F. is no longer in phase with that of the circuit; the two are thereby added, thus doubling the normal E. M. F. and bringing increased strains on the insulation and the opening devices.	5. The motor does not generate E. M. F. when it is disconnected from the circuit.
CAUSES WHICH MAY ACCIDENTALLY STOP A MOTOR.	
1. Momentary lowering of E. M. F. caused by short-circuit on the line, or by accident at another motor, or by error in synchronizing a generator, or by the "switching over" of the motor from one circuit to another, is apt to cause the motor, particularly if carrying load, to fall from synchronism and come to rest.	2. Momentary lowering of E. M. F. causes momentary decrease in speed.
2. A heavy load, even momentary, may exceed the limiting torque and cause the motor to drop from synchronism, even though the load be removed immediately. The connection between generator and motor is rigid.	2. An excessive load receives the stored energy of the motor and of the load itself as the motor falls; when the excess load is removed the motor speed increases again. The connection between generator and motor is elastic.
3. If the generator speed suddenly increases, a motor carrying a load having inertia may be unable to increase its speed quickly without exceeding the limiting torque, which will cause the motor to stop.	3. The motor readily follows changes in generator speed.
SUMMARY.	
1. The motor is an *active* element in the system; it acts as a generator in impressing its own wave form, its E. M. F. and its fluctuations upon the circuit. These fluctuations may be caused by an intermittent load.	1. The motor is a *passive* element in the system. Each motor attends to its own work and does not try to run the system.

SUMMARY.—Continued.

Synchronous Motor.	Induction Motor.
2. The motor is a sensitive element in the system. Its successful operation is dependent upon a proper relation between the design of the motor itself and of other machines connected with the system. Its successful operation also depends upon the proper adjustment and freedom from speed fluctuation in generators and other motors. It is liable to momentary variations from normal conditions, such as a sudden overload and sudden increase of generator speed or a momentary fall in E. M. F.	2 The motor is not sensitive to differences in the design of other apparatus operating on the same system.
3. The motor requires skill and care on the part of the attendant for starting, for readjusting and for keeping the various brushes and auxiliary apparatus in proper condition.	3. No experience and electrical skill are required of the attendant and there is little or nothing to get out of order either through carelessness or design.
4. The power factor is under the control of the operator and the current may be made leading or lagging. Instruments are necessary in order that proper adjustments may be made by the attendant.	4. The motor has a definite power factor, depending upon the load; the out-of-phase current does not vary greatly at different loads. The changing load, therefore, has comparatively little effect upon the drop in voltage, and in regular service there is little liability that the motor will disturb the E. M. F. of the circuit.
5. The motor and its operation are complex and involve many possibilities of accident.	5. The motor and its operation are simple and reliable.

The synchronous motor is obviously not suitable for general distribution of power, owing particularly to its lack of starting torque, the skill required in attendance and the liability of the motor to stop if the conditions become abnormal. These objectionable features, however, are of much less importance when motors are installed in sub-stations or are of sufficiently large size to justify an attendant.

The characteristic of the synchronous motor which may be particularly advantageous is the fact that the power factor of the current can be varied and that the current may be made leading. In this way the current required and the drop in the generator

and transmission circuit may be reduced. If the motor is used on a circuit supplying induction motors the synchronous motor may be given a leading current, thus neutralizing the lagging current to other motors. The extra current taken by the synchronous motor for this compensation necessitates a larger size than would otherwise be required.

The characteristic of the induction motor which is usually regarded as most unfavorable in comparison with the synchronous motor, is the fact that its current is always a lagging current. In a comparison with synchronous motors only large sizes should be included, as synchronous motors of small size are not to be seriously considered in practical work. The induction motors of large size have relatively high power factors, *i. e.*, the out-of-phase current is small. Moreover, this current is definite in kind and nearly constant for different loads, so that it is a definite and constant element which may be provided for. It may therefore create less disturbance on the system than the out-of-phase current of the synchronous motor, which is either lagging or leading, large or small, depending upon the intelligence and care of the attendant and upon other conditions. In one case the voltage of the system is under the control of the attendant in the power-house and the lagging current to induction motors which are running with either constant or varying load is practically constant. On the other hand, when synchronous motors are used, the voltage of the system is dependent upon all the motors, and uncertain or disastrous results are liable to be caused by adjustments by the various motor attendants. In many cases it is far better to provide the generators and circuits suitable for supplying the lagging current required by induction motors, rather than to attempt to gain the theoretical advantages attending the use of synchronous motors, as the securing of these advantages requires that so many conditions be favorable. At best the synchronous motor is less satisfactory to operate and is far more sensitive to abnormal or emergency conditions than the induction motor.

The foregoing considerations will indicate why it is that the induction motor has taken such a leading place, while the synchronous motor has been less favored and is now rarely considered seriously as a competitor of the induction motor except in large sizes.

II.—The Rotary Converter.

The rotary converter is in its relation to the transmission system essentially a synchronous motor. The foregoing characteristics of the synchronous motor, except those which involve a load upon the motor, apply also to the rotary converter. The starting, however, is somewhat simpler, as there is no load to accelerate except the armature. No separate exciter is necessary as the converter can furnish its own direct current for exciting. A converter may be compound-wound so that as it is loaded the increased excitation changes the out-of-phase current in such a way as to compound the voltage, thus overcoming the drop which would otherwise occur in generator and transmission circuits; whereas, the synchronous motor would cause a falling off in voltage. The rotary converter is generally used in units of considerable size placed in sub-stations having skilled attendants. For these reasons the operation of rotary converters does not involve so many difficulties as that of synchronous motors.

Direct current is obtained from alternating circuits, either by the rotary converter or a motor-generator, in which either a synchronous or an induction motor is employed.

The rotary converter has the advantage over the motor-generator in point of cost, there being but one machine instead of two; in point of efficiency, there being the loss in one machine instead of two; and in its effect upon the voltage of the transmission system, as it may be compounded to overcome the drop which would otherwise occur in generator and transmission circuit. On the other hand, the E. M. F. of the direct current delivered by the converter depends upon the E. M. F. received; whereas, the E. M. F. of a motor-driven generator is independent of the E. M. F. of the supply circuit and may be adjusted or compounded as may be desired. It is found in practice, however, that the voltage delivered by a rotary converter can be satisfactorily adjusted and controlled by regulating devices or by compounding so that usually the close relation between the E. M. F.'s at the two ends of the converter is not disadvantageous, provided the E. M. F. of the supply circuit is reasonably constant.

This statement applies to those cases in which a practically constant voltage is desired. There are, of course, special cases in which the voltage is to be adjusted over a very wide range or where for other reasons the motor-generator is to be preferred.

In many cases the motor may be used either with or without transformers, whereas they would be required with a rotary converter.

A motor generator employing a synchronous motor does not seem to possess any essential advantage over the converter except that sometimes the motor may receive the line voltage without transformers, and in some cases the independent control of the direct current voltage is desired. The use of the synchronous motor does not remove the objections to the rotary converter, which are based on the fact that it is a synchronous machine.

A motor-generator employing an induction motor has the advantage of employing induction instead of synchronous apparatus; thereby securing many of the advantages set forth in the comparison between synchronous and induction motors. Circuits which are supplied by generators in which the speed has a rapid and periodic fluctuation, or in which for any other reason the use of a synchronous machine is impracticable or undesirable, may nevertheless operate an induction motor driving a generator with full satisfaction. The various characteristics of the induction motor under emergency conditions, such as sudden overload, momentary interruption or lowering of the voltage of the supply circuit, may cause little or no inconvenience if the induction motor is used, whereas, it might cause serious interruption to a rotary converter or a synchronously driven generator. The induction motor driving a generator is also to be preferred where units are quite small and the attendance is unskilled. The rotary converter, like the synchronous motor, is unsuited for general distribution in small units.

The foregoing statements and comparisons involving the rotary converter doubtless comprise the principal reasons why this apparatus is being so widely adapted and is in such general use. To indicate the wide use of this apparatus it may be stated that the Westinghouse Electric and Manufacturing Company, with which the writer is connected, has sold over 400 rotary converters. Of this number 30 per cent. are for a frequency of 60 cycles or more. The aggregate output is over 165,000 K. W.

Most of this apparatus is now installed and is in successful operation. In fact, the difficulties in connection with the installation and operation of rotary converters on circuits which are suited for them are trivial and do not materially differ in amount

from those which may be expected to occur in connection with other kinds of apparatus.

The very wide use of the induction motor and the rotary converter is an established fact, and it is believed that many of the reasons for their selection in preference to other kinds of apparatus have been set forth in the foregoing notes.

III.—The Alternator.

Many of the specific relations between the induction motor and the rotary converter and the supply system have been indicated. There is obviously a close relation between the alternator and the apparatus which it supplies. The conditions are radically different from those involved in incandescent lighting. An alternator which may be quite satisfactory for lighting purposes may be highly inadequate for successfully supplying current for either induction motors or rotary converters.

For supplying current to induction motors an alternator should have good inherent regulation. The lagging current taken by induction motors requires a greater increase in field current for maintaining a given voltage than is required when the load is non-inductive. In order that the field current may not be excessive, the generator should be properly proportioned to have close regulation. The adjustment of the field current by external devices is not a wholly satisfactory substitute for close inherent regulation. Suddenly changing loads or the throwing on or off of motors causes fluctuations in voltage, as the external devices cannot act quickly enough to prevent the disturbance. The necessity of good inherent regulation is all the more necessary where the motors are large in proportion to the size of the generator and where loads are fluctuating.

For the operation of rotary converters the generator speed should be uniform. Engines which are sufficiently uniform in angular velocity to enable generators to run successfully in multiple may nevertheless be unsuited for operating rotary converters or synchronous motors. It is preferable also that generators for operating rotary converters should have good inherent regulation, not only in order that the E. M. F. may be maintained at heavy loads, but also for the purpose of holding the converter rigidly in synchronism. If the alternating field is comparatively weak, as is usual in machines of poor regulation, there may be a shifting of the magnetic field back and forth with different arma-

ture currents, quite similar to the shifting of lead in direct current machines. It is obvious that if the effective position of the field poles may shift back and forth, this shifting is comparable with fluctuations in generator speed, and becomes a source of unsteadiness in the system which may contribute to the "hunting" of rotary converters. This shifting may occur also in a machine having a strong field if a large proportion of the magnetizing force is absorbed in the iron of the field magnet, *i. e.*, a machine with a saturated field. Such a machine may have good E. M. F. regulation, and still be of an inferior type for the driving of synchronous machinery.

It follows, therefore, that a generator which is to supply induction motors or rotary converters should be selected with reference to the service which it is to supply. In some cases unsatisfactory results have been obtained in the use of motors or converters, duplicates of those which have given full satisfaction elsewhere. The trouble has been located in fluctuating speed or in the characteristics of the alternator supplying the current.

A transmission system must be considered as a unit and the inter-relation between the alternator and the apparatus to which it supplies power must be fully considered.

The theoretical arguments which are occasionally urged against the alternating system, the induction motor and the rotary converter, find their most effective answer in the plants which are now in operation and in their record of service.

The induction motor and the rotary converter to-day represent the survival of the fittest, and confirm the judgment of those engineers who have consistently and persistently advocated their use.

A paper presented at the 18th Annual Convention of the American Institute of Electrical Engineers, Buffalo, August 22nd, 1901, Vice-President Dunn in the Chair.

THE CONTROL OF HIGH POTENTIAL SYSTEMS OF LARGE POWER.

BY E. W. RICE, JR.

The enormous increase in the use of electricity for lighting, traction and power has necessitated important changes in our generating stations. As the areas to be served have rapidly increased, corresponding increases have been made in the size of these stations and in the electrical potentials employed. The change has been due, not only to the great natural growth but to the consolidation of generating machinery into fewer stations. Instead of a number of separate stations, containing relatively small units producing electricity at comparatively low voltage with relatively large transmission losses, we now frequently find one large central station, containing generating units of great size delivering electricity at a high potential. Dynamos of 2,000 to 5,000 kilowatts capacity are displacing those of 200 to 500 kilowatts, and pressures of 5,000 to 15,000 volts those of 1,000 to 2,000 volts. The design and manufacture of large generating units of this character have called for engineering skill of a high order, and it can now be fairly claimed that the production of such machines has been reduced to an exact science.

The rapid evolution and present perfection in dynamo design have been due to the skill with which the various problems have been solved by the designing engineers and to the ease with which the data based upon machines of relatively small size were applied to those of larger size.

It is evident, however, that great advances in the capacity and voltage of generators would be useless, if not positively dangerous, unless adequate means for controlling and switching the electrical current were at hand. The evolution of the dynamo was for a time more rapid than that of the devices for controlling and switching currents of large volume and potential. As a result, a number of machines of large size were placed in operation with comparatively inadequate methods of switching and controlling. The energy and power which can be safely concentrated in a single central station is obviously limited by the amount of current and voltage which switching devices can safely handle. This fact was especially forced upon the attention of the writer at the time when the company with which he is connected took the contract for the equipment of the generating station of the Metropolitan Traction Company of New York. This station was to contain eleven three-phase dynamos, each of 3,500 kilowatts output at 6,600 volts. In order to realize the full economy of such a station, it was, of course, necessary that all the generators should supply current to a common bus bar, and that from these bus bars the current should be distributed through feeders to a number of sub-stations. The sub-stations were to contain rotary converters, frequently working in multiple with large storage batteries on the direct current side. The characteristics of such a load prevented any reliance being placed upon the opening of the exciting circuit of the generators in case of the necessity of a general shut-down, as the rotary converters would, under certain conditions, supply sufficient magnetizing current to excite the generators, even with the field windings of the generators unexcited. It became, therefore, essential to produce a switching mechanism which would enable the generators to be connected and disconnected from the bus bars with certainty and safety under all conditions of load, even up to a short-circuit, and also that the various feeders supplying the sub-stations should be capable of the same treatment. Three types of switching devices were available for this work and were carefully considered :

1. Switches breaking the circuit in the open air.
3. Switches arranged to break the circuit in an enclosed air space.
3. Switches arranged to break the circuit under oil.

Switches of the first type (open air) were impracticable, because the space demanded to make such switches operative could not be provided.

Switches of the second type (enclosed air) had no such limitation, but oil-break switches were found to meet the conditions more perfectly. Tests conducted showed that energy up to 2,000 or 3,000 kilowatts could be controlled in a single oil switch at potentials as high as 15,000 volts, which was the limit of the apparatus at our disposal at the time. Switches of this type, however, as large as was considered necessary, required an amount of oil per switch so great as to be objectionable, in view of the large number of switches required for generators and feeders. The problem then was to produce a switch which would retain all the advantages of the usual oil switch and at the same time minimize the quantity of oil.

The type which was finally evolved and employed in the Metropolitan installation has shown itself in practice to be remarkably successful. It is known as the Form "H" Oil Switch by the manufacturers, and was designed by the writer, with the assistance of Mr. E. M. Hewlett. It was described by Mr. J. E. Woodbridge in the *Electrical World and Engineer* of April 14th, 1900. Reference to this article will give the details, which I need not here repeat; I shall simply outline the principal features.

The switch, as designed for three-phase circuits, consists of three double-pole, single-phase switches, or elements. Each single-phase switch is contained in a fireproof cell, but all three switches are designed to be operated simultaneously. Each single-phase element consists of two brass cylinders or cans, one can for each pole. The in-coming lead is attached to one of the cans and the out-going lead of the same phase to the other. Each cylinder is nearly filled with oil and is covered by a metal cap which carries a long insulating sleeve. Two copper rods joined by a metallic cross-head and forming together a U-shaped conductor, slide through the insulating sleeve and fit into tubular contacts at the bottom of the cans when closing the circuit. The cross-head of each U-shaped conductor is attached to a wooden rod, which extends through the top of the cell or casing which encloses the switch, and is in turn attached to a metal cross-head operated by an air motor or an electric motor, as the case may be. The three phases are seen, therefore, to be broken or closed simultaneously. When the three sets of U-shaped

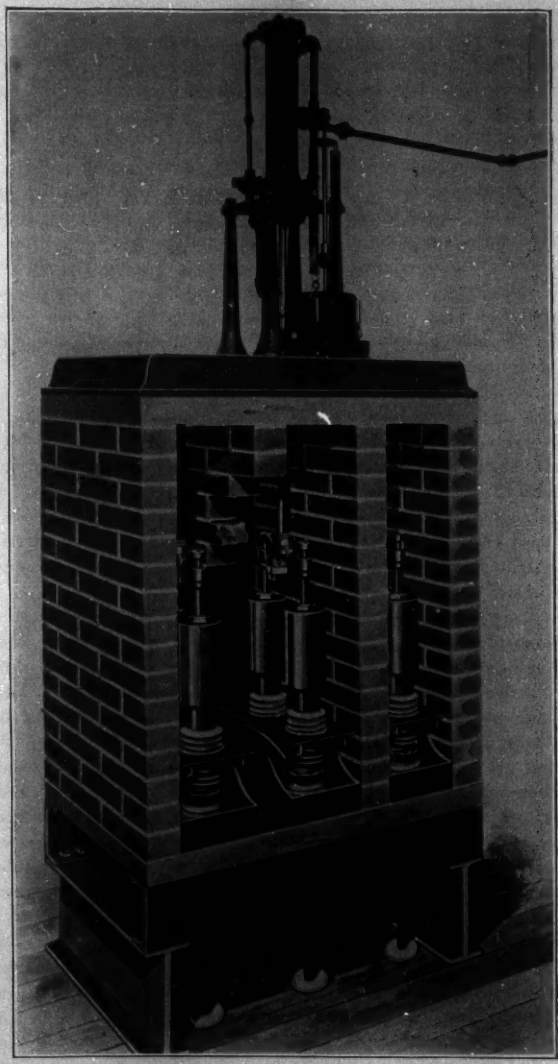


Fig. 1.—Pneumatically Operated Type H Switch, Metropolitan Traction Company's Station.

conductors are lifted, the circuit is broken under the oil at two points in each phase, or six points in each complete three-phase switch. The range of movement of the cross-head varies with

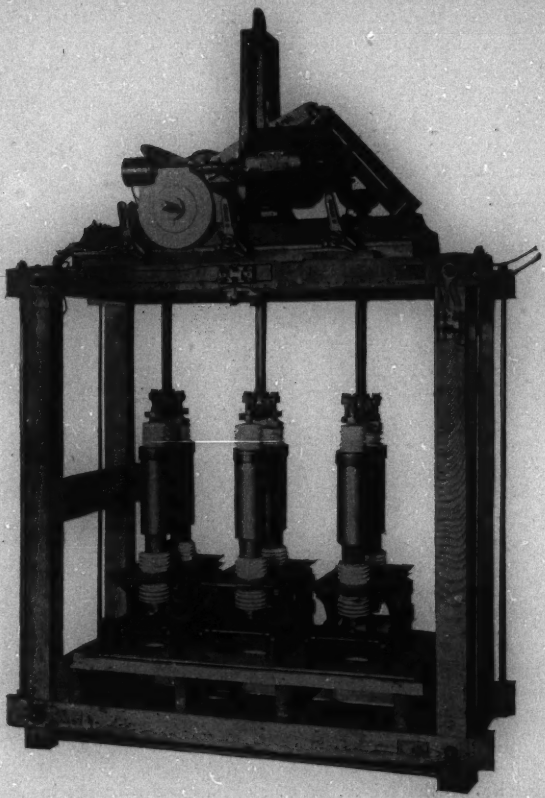


Fig. 2.—Electrically Operated Type H Switch for the Manhattan Railway Company, with brick partition removed.

the potential to be controlled, *e. g.*, it is 12 inches in the switches in the Metropolitan station for 6000 volts, and 17 inches in the switches for the Manhattan station for 12,000 volts. The brass

cans are lined internally with fiber to prevent the arc from jumping from the rod to the metal of the can when it is drawn up through the oil. Each switch unit stands alone on its own foundation, with the three phases in three separate cells or spaces separated by brick walls. These brick partitions act as barriers and prevent any possible burn-out in one cell from

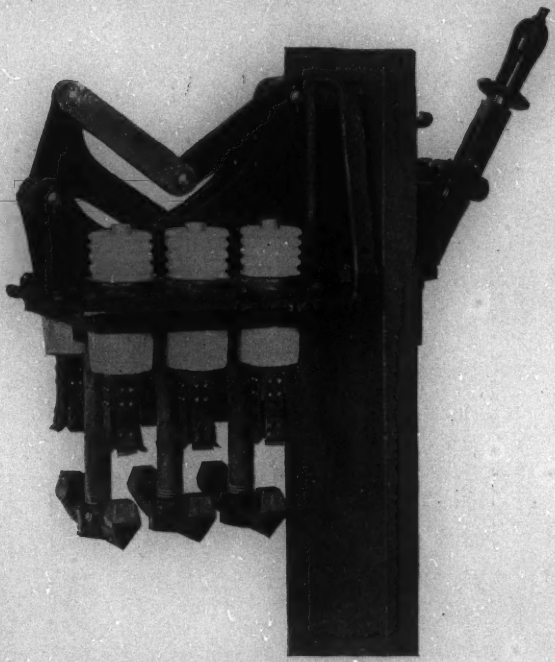


Fig. 3.—Form FK Oil Break Switch.

spreading to the others. As an opening of two legs breaks a three-phase line, an arc in one cell will not incapacitate the switch. The circuit breaker or switch differs radically from older forms in the separation of the phases as indicated, and also in the separation of the contacts for each phase, in two separate oil pots. This separation of the terminals of each phase gives two separate arcs, each enclosed in a space well removed from

the others, so that the possibility of an arc communicating from one pole to another is obviated. It will be seen that in breaking a three-phase circuit, the arc is produced in six independent oil pots. This method of construction, together with the separation of the phases in separate fireproof compartments, accounts for the unusual effectiveness of the switch in practical operation. The general construction of the switch is clearly shown in the accompanying illustration.

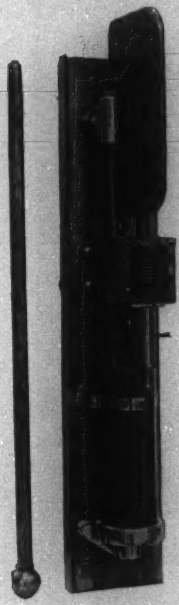


FIG. 4.—Expulsion type switch.

Fig. 1 shows the switch used in the installation of the Metropolitan Traction Co., New York. It is designed for 6600 volts and 300 to 800 amperes.

Fig. 2 shows the same switch as modified to suit the conditions of the Manhattan electric installation. On account of the higher voltage the oil pots are larger and a larger opening of the circuit is provided. The twelve covers for the oil pots are replaced by porcelain. It is designed for 12,000 volts and 300,800 amperes.

Fig. 3 illustrates the enclosed air tube type of switch already mentioned. This switch has given most excellent results on high potential work.

Fig. 4 shows the form FK, or tank oil switch, without tank for containing oil.

Fig. 5 is a reproduction from a photo taken at Kalamazoo of a special form of open air switch. The switch was opening a circuit of 25,000 volts and 60 amperes at the time when the photograph was taken.

It was at first thought that the use of oil switches for the control of high potential circuits would possibly result in resonance effects, particularly in circuits containing considerable capacity, such as underground cables or long overhead lines. A number of experiments have been conducted and the weight of evidence seems to be in favor of the oil switch as avoiding these

effects. It has been found as an interesting fact that under the conditions described considerable disturbance due to resonance may occur upon the *closing* of a circuit. This is naturally independent of the character of the switch employed; it may

Fig. 5.—Air Break Switch (Kalamazoo Test).

occur equally well with an oil, an enclosed air, or an open air switch.

Upon the rupture of the circuit, however, the results obtained from many tests indicate that open air switches are liable to produce heavy resonance effects while the enclosed air

and the oil switch are practically free from such effects. Extensive experiments to determine this point were conducted prior to the production of the switches for the Metropolitan and Manhattan stations. Very recently experiments of a more severe character have been conducted at Kalamazoo, Mich. These tests were made at from 25,000 to 40,000 volts with from 1,200 to 1,300 K. V. A. of highly inductive load, the power factor being from 40 to 60 per cent. The switches tested were the cylindrical oil switch, already described (Metropolitan type); an oil switch in which all the terminals were enclosed in a single tank of oil, called the tank oil switch, type "K"; a switch of the expulsion air tube type; and an open air switch in which the terminals were simply separated long distances in free air. In making these tests an oscillagraph was used to determine the time of break and other interesting effects, and a camera to photograph any particular instructive phenomena.

The long break open air switch, which operates upon the principle of drawing a long arc in the open air, opened the circuit at 25,000 volts, but required several seconds of time and drew such a long arc as to be impracticable. At 40,000 volts the arc held and flared to a total distance of over 30 feet until it struck the line and short-circuited the system, producing at the same time high-voltage oscillations equal to two or three times the normal potential of the system. It would therefore seem that the open air switch was generally unsuitable for the control of high-voltage systems of large powers, as even where sufficient room is available for their use, the production of high resonance effects tends to endanger the system. These tests also show that wherever a short-circuiting arc occurred in the open air, electric oscillations of high voltage resulted. These were probably due to the rapid alternate extinguishment and formation of the arc during its period of interruption, the arc acting somewhat in the manner of a Wehnelt interrupting device. The dangerous character of short-circuiting arcs emphasizes the need of the precautions which I shall mention in this paper; having in mind the avoidance, as far as possible, of such accidental short-circuits.

The expulsion tube air switch operated up to 25,000 volts, but failed at 40,000.

The "K" oil switch operated satisfactorily on 1,200 to 1,300 K. V. A. up to 25,000 volts, but at 40,000 volts it spat fire and

occasionally emitted black smoke, thus seeming to be working at the limit of its capacity. No attempt was made to open short-circuits with the "K" switch.

The "H" oil switch never failed to open 1,200 to 1,300 K. V. A. at any voltage up to the maximum employed, 40,000; the circuit opening noiselessly and without the appearance of fire or emission of smoke at the switch. It was used as an emergency switch in all the tests to open *short-circuits* on 25,000 to 40,000 volts. The results of these and other tests, and the continued effective operation of the type "H" switch in the Metropolitan station indicate that this type of oil switch will safely control circuits of practically unlimited power at potentials considerably above 40,000 volts, probably as high as 100,000 volts.

The character of the break when operating properly was the same in all the switches except the open air type. In opening, the arc held for a number of half-waves from 6 to 18 and then broke at zero value without disturbance of the system. With the oil switches no traces of oscillation were noticed before the break, and no traces of rise of voltage. With the expulsion air switch, traces of oscillation were seen for a number of half-waves before the final break, and in consequence a slight voltage rise occurred.

I will not attempt to describe the numerous observations made at the Kalamazoo tests, as these will undoubtedly be given to you by our President, who supervised these tests and to whom I am indebted for the information which I have given regarding them.

In addition, however, to the production and use of a switch, which will be as safe and reliable as engineering skill can make it, there are certain other factors which should be considered in connection with the control of current for high-potential stations which should be taken into consideration by the electrical engineer. It should be constantly kept in mind that no apparatus can be absolutely free from accident, no matter how carefully designs are constructed. The engineer should, therefore, carefully consider the possible effect of any accident, with particular reference to the possibility of an accident to one element involving other apparatus. The layout should be such that an accident to one element could not of itself, or in consequence of a chain of accidents, result in a breakdown of the entire generating station, even for a short time.

The mechanical engineer has considered this point and met it with a fair degree of success in the large modern central station with the fire-proof boiler house and the frequent subdivision of this boiler house into two or more portions by suitable fire walls, as in the case of those of more than one story.

The general employment of a duplicate system of steam piping, or its equivalent, also provides a reasonable safeguard against failure of supply from accidental disarrangement of a steam system. The steam engines in well arranged stations, being important units, are placed a sufficient distance apart, and so disposed, generally, that an accident to one will not easily involve other units. This is also true of the dynamos which are directly coupled to the engines.

The switchboard with its switches for controlling and appliances for measuring the output of the generating station, the cables leading from the generator to the switchboard, the location of the bus-bars, and the disposition and arrangement of the feeder cables for distributing the current, have not as a rule been given that serious attention which their importance deserves. In fact, the consideration of the electrical controlling devices and the wiring of the station has been apparently left to the last, and it is frequently the case that a generating station containing apparatus of great value has been jeopardized by the lack of careful design of the switching appliances. Stations designed to deliver a normal output of from 5,000 to 10,000 kilowatts, at relatively high pressures, say 5,000 volts or upwards, frequently contain switches for controlling the generators and the feeders mounted upon the face of a long continuous panel, and so crowded together that in case of failure to open the circuits the resulting arc would be almost certain to involve adjacent switches and even possibly cripple the station for a time. The bus-bars are also often so disposed that an arc may easily start thereat or at least so that an arc, if started for any cause, would be liable to seriously damage the switchboard.

The same methods frequently obtain in regard to the manner of installing the conductors; high tension and low tension conductors being often mixed together and the conductors so arranged that in case of an injury to one, other of the conductors leading from the generators or from the switchboard out of the station are in danger of being involved.

These methods have probably arisen from the fact that up to

a comparatively recent period the service of a city for lighting and for power has been separated among a number of different stations, each of a relatively limited amount of power. In case of the failure of any individual unit in such case, as of the generator, switchboard, or other apparatus, the damage was small, owing to the limited energy available. A shut-down, even of the whole station, was comparatively unimportant. However, the case is quite different with the large modern station with output of from 10,000 to 100,000 horse-power, which is designed to supply electrical energy for a large portion of a city's needs, combining frequently electric power for traction purposes, electricity, for lighting, etc. The economies expected of such stations —lower cost of operation, smaller investment, and greater economy in coal and in steam—due to the better load-curve obtained by the concentration of loads of large area and of various character in one station, as well as to the higher efficiency of the large units, are familiar to all electrical engineers. I am inclined to think, however, that the possible dangers of such a concentration of energy have not been fully realized. The failure of such a station, even for a brief period, would be a disaster which, with proper design, need not occur.

I will briefly outline the principles which I believe should govern in the layout of such a central station, the details of which may naturally be varied considerably to suit local conditions. It should be kept in mind that I am discussing stations of normally large output, say 5,000 kilowatts and over, although many of the principles mentioned could probably be applied with advantage to stations of smaller size. Broadly speaking, I would carry the principle of subdivision into units as far as practicable; the units to be chosen with respect to the size of the station, character of load-curve, etc. The boiler house, as already stated, should be subdivided into two or more distinct portions, so that injury to one will not involve the entire steam system. Fortunately, the foundations, masonry and mounting of boilers are so essential and of such a nature that damage to one unit is not liable to involve another. At the same time, it is important that the boiler house should be divided into two or three sections, separated from each other by brick partitions. The steam piping should be in duplicate or a substantial equivalent, and so arranged that the bursting of a steam main cannot flood all the boiler rooms with steam or stop the entire flow of steam to the engine room.

The engines, with the dynamos coupled thereto, may be placed in one large room, provided this room is of sufficient size to enable the units to be placed at proper distances apart. The switchboard should preferably be placed in a separate room, so that any accident to the engine or to the steam piping will not injure the switchboard operator or the switchboard mechanism. The electrical conductors from each dynamo should be led to the switchboard as far apart as possible from those of other units. Each set of conductors should be led to its own switch. Each switch should be of ample capacity to interrupt the entire output of the generator at full voltage and even take care of the concentration of the entire load of the station, as in a short-circuit. This switch should be placed in a cell of fireproof material and preferably electrically controlled from a central point. If so disposed, these switches may be placed reasonably close together, but the partitions should be such that any one of the switches could arc to destruction without involving the switch of a neighboring generator. Switches should be in duplicate, so that in case of failure of one, another switch will be in readiness. Especial care should be taken, in leading the conductors from the switches to the bus-bar, to keep the conductors as far as possible from those of neighboring units.

The bus-bar or bars should preferably be in duplicate, or some equivalent arrangement such as sectional subdivision should be adopted. Bus-bars should be carefully protected in fireproof compartments so arranged that it would be impossible for any arc to short-circuit from one conductor to another or for it to be injured by an arc caused by the destruction of any of the generator or feeder switches. The same care should be taken to isolate the conductors leading from the bus-bars to the feeder switches. The feeder switches should also be in duplicate; that is, two separate sets of switches on each feeder in series with each other when feasible, or the conductors leading to a group of feeders may be joined together by a switch placed in series therewith controlling a group of feeders. Each group series and each of the feeder switches should be mounted in its own separate fireproof compartment and preferably controlled electromagnetically from a distance. The conductors leading from the feeders out of the station should not be massed together in one conducting trench or well, but should be subdivided into as many groups as circumstances will permit.

The constant aim throughout the entire station should be to limit the normal flow of energy in a given space to a pre-determined amount, preferably for example, to that of the generator unit which has been selected, or in the case of the feeders leading outside the station the normal flow of a group may be limited to that delivered to any one sub-station.

It is obvious that the arrangement of switchboard, as described, will occupy more space than the ordinary panel type. The total space occupied, however, is but a small portion of the total space required for the generating plant, and it is believed that the precautions recommended are essential to the continued success and reliability of large generating plants. Such separation of the switches, etc., makes some method of control from a distance very desirable. The motors used for operating the switches may be either pneumatic or electric. The control of these motors should preferably be electric in all cases. By adopting electric control from a distance, it is possible to combine all the switches required for the generator, feeders, etc., upon a small keyboard under the observation and control of a single operator. It is also possible to place this operator in such a position that he will have a comprehensive survey of all the measuring and controlling devices needed for the station, and at the same time be free from danger in case any of the apparatus should fail to perform its work. Under such circumstances the operator is much less liable to make a mistake, and it is believed that having taken such precautions accidents even of a trivial character will be more unlikely to occur. In laying out the electrical devices for such a station the utmost simplicity should be aimed at; not a single instrument, conductor or switch being placed in the station that has not been carefully considered and felt to be essential. It is better to err on the side of simplicity than of complexity.

A paper read at the 150th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902, President Steinmetz in the chair.

STREET ILLUMINATION AND UNITS OF LIGHT.

BY. W. D'A. RYAN.

Photometry.

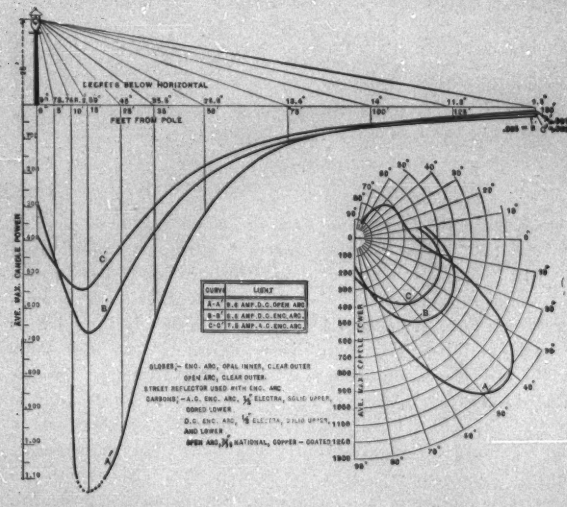
In order to make photometric comparisons of open and enclosed arcs I have found it necessary to work as far as possible with fixed conditions such as current, voltage, and position of arc. The widely different results of various investigators are in part due to insufficient attention to these essential points, particularly the latter. A photometer with a reasonably long bar is also indepensible. This should be provided with an adjustable revolving sector disk by which the light from the arc can be reduced so that all settings can be made in the most accurate part of the scale. This arrangement permits working with a single standard and with light of low intensity which decreases the error introduced by color difference. A rotating crane is required for elevating and depressing the lamps in order to measure the light from different angles in the vertical plane.

A Bunsen photometer as described can be operated by three observers, but I have found four more satisfactory; one devotes his time entirely to making settings of the screen, the second maintains the current and voltage at the proper values, the third notes the position of the arc, and the fourth records the readings taken when the fixed quantities are correct. After working together for a few days such a complement can reproduce the average characteristics of light distribution of arc lamps to within 5 or 6 per cent. of the mean which, for arc lamp photometry, is considered very satisfactory.

CANDLE POWER CURVES.

The curves in Fig. 1 were obtained by the method described. To render the curves of commercial value the tests were carried on with lamps equipped as they ordinarily would be for street lighting, that is to say, the open arc lamp was trimmed with 7/16″ National carbons and was provided with a clear globe.

The enclosed arc lamps were trimmed with high-grade carbons and were provided with opal enclosing and clear outer globes


DEGREES BELOW HORIZONTAL
FEET FROM POLE
AVE. MAX. CANDLE POWER
CURVE
LIGHT
A-A 9.6 AMP. D.C. OPEN ARC
B-B 9.6 AMP. D.C. ENC. ARC.
C-C 7.5 AMP. A.C. ENC. ARC.
GLOBES:- ENC. ARC, OPAL INNER, CLEAR OUTER
OPEN ARC, CLEAR OUTER.
STREET REFLECTOR USED WITH ENC. ARC
CARBONS:-A.C. ENC. ARC, ½" ELECTRA, SOLID UPPER, CORED LOWER
D.C. ENC. ARC, ⅛ ELECTRA, SOLID UPPER, AND LOWER
OPEN ARC, 7/16 NATIONAL, COPPER - COATED

Street Illumination Curves. Candle Power Curves.

FIG. 1.

and street reflectors. All lamps were adjusted so as to consume approximately equal watts at the arc.

First confining our attention to the direct current lamps, curves A and B, we will observe that the open arc lamp gives a greater maximum candle power (which, of course, is not by any means a measure of its usefulness). The enclosed arc lamp gives a stronger light through the most useful angles of from say 3° to 10° below the horizontal and from the shape of the curves it is self-evident that the distribution from the latter is more uniform.

ILLUMINATION CURVES.

We are not, however, particularly interested in the candle power of the lamps. We desire principally an even illumination along the street surface, and we wish mainly to project the light as far from the source as possible.

To make this comparison it is therefore necessary to convert the "candle power curves" into "illumination curves" giving the candle feet along the ground on surfaces normal to the rays of light.

The illumination curves in Fig. 2 are plotted for lamps 25 feet above the ground and at intervals of 300 feet. By introducing the element of distance we find that the strongest light received on the ground from the open arc is not projected at an angle of 45° as indicated by the candle power curves, but falls at an angle of about 60° below the horizontal, illuminating the ground brilliantly at a distance of about 15 feet from the pole, thus showing that in order to properly compare illumination of differ-

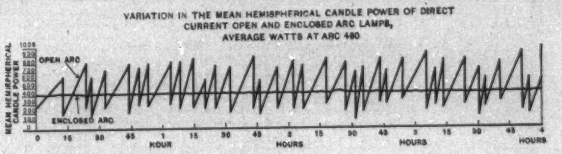

VARIATION IN THE MEAN HEMISPHERICAL CANDLE POWER OF DIRECT CURRENT OPEN AND ENCLOSED ARC LAMPS, AVERAGE WATTS AT ARC 480
MEAN HEMISPHERICAL CANDLE POWER
OPEN ARC
ENCLOSED ARC
HOUR
HOURS
HOURS
HOURS

FIG. 2.

ent lamps we must look to the surface illumination curves rather than the candle power curves, as previously stated.

Further analyzing the curves it will be observed that the illumination of objects on the street surface from the open arc lamp is brighter up to a distance of about 100 feet from the source. Beyond this the light from the enclosed arc lamp is the strongest, and at 150 feet it exceeds the open arc by considerable, and this is made still more effective by the absence of strong light in the immediate vicinity of the lamp. This advantage is so obvious that further comment seems unnecessary.

Comparisons so far have been confined to fixed conditions with respect to current, voltage and the position of the arc.

We have next to consider the variations caused by the wandering of the arc, variations of potential between picking up and feeding points, fluctuations due to drafts of wind, non-homo-

geneity of carbons and other changes introduced by the inherent peculiarities of the different lamps.

VARYING ARC.

Open arc lamps ordinarily pick up at about 45 volts and feed normally at about 50. The light projected in any direction is approximately proportionate to the amount of crater area visible from any point in that direction, and the amount of crater area visible varies greatly with the small change in the length of the arc introduced by a difference of 5 volts.

Where lamps have been installed for a considerable period and have not received proper attention, the voltage variation

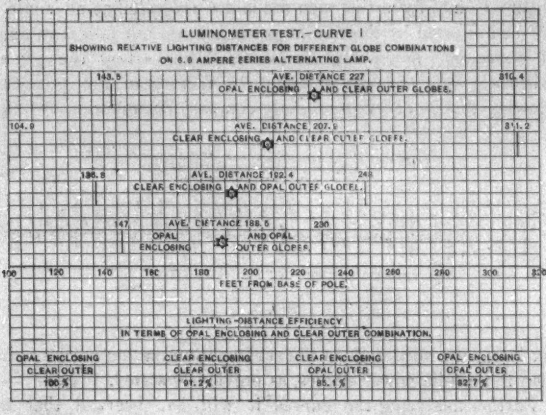

LUMINOMETER TEST.–CURVE I
SHOWING RELATIVE LIGHTING DISTANCES FOR DIFFERENT GLOBE COMBINATIONS
ON 6.6 AMPERE SERIES ALTERNATING LAMP.
AVE. DISTANCE 227
OPAL ENCLOSING AND CLEAR OUTER GLOBES.
AVE. DISTANCE 207.9
CLEAR ENCLOSING AND CLEAR OUTER GLOBES.
AVE. DISTANCE 192.4
CLEAR ENCLOSING AND OPAL OUTER GLOBES.
AVE. DISTANCE 188.5
OPAL ENCLOSING AND OPAL OUTER GLOBES.
FEET FROM BASE OF POLE.
LIGHTING-DISTANCE EFFICIENCY
IN TERMS OF OPAL ENCLOSING AND CLEAR OUTER COMBINATION.
OPAL ENCLOSING CLEAR OUTER 100 %
CLEAR ENCLOSING CLEAR OUTER 91.2 %
CLEAR ENCLOSING OPAL OUTER 85.1 %
OPAL ENCLOSING OPAL OUTER 82.7 %

FIG. 3.

may greatly exceed the normal limits. The lamp is then said to be working between a sluggish feed and the hissing point, and as the arc feeds on an average cycle of about ten minutes, varying irregularly between 5 and 15 minutes the candle power and illumination shown in Figs. 1 and 2 represents only instantaneous values which occur at very irregular intervals.

The enclosed arc lamp is particularly free from this variation. The arc is about $\frac{3}{8}$" in length and the lamp feeds in about 4-hour cycles varying irregularly between 3 and 5 hours, and the feed is an instantaneous drop and pick up to the original

position. There is, however, a rise of voltage due to the heating of the shunt coils which may amount to 10 or 15 volts. This is a gradual rise, taking place during two or three

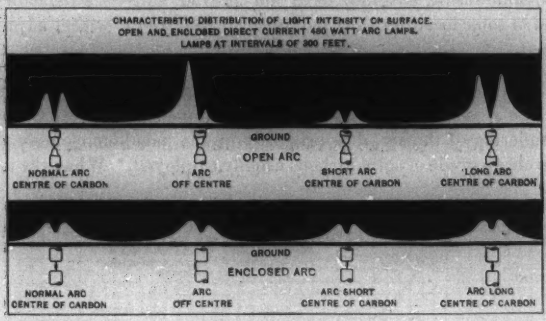

CHARACTERISTIC DISTRIBUTION OF LIGHT INTENSITY ON SURFACE.
OPEN AND ENCLOSED DIRECT CURRENT 480 WATT ARC LAMPS.
LAMPS AT INTERVALS OF 300 FEET.
GROUND
OPEN ARC
NORMAL ARC CENTRE OF CARBON
ARC OFF CENTRE
SHORT ARC CENTRE OF CARBON
LONG ARC CENTRE OF CARBON
GROUND
ENCLOSED ARC
NORMAL ARC CENTRE OF CARBON
ARC OFF CENTRE
ARC SHORT CENTRE OF CARBON
ARC LONG CENTRE OF CARBON

Fig. 4.

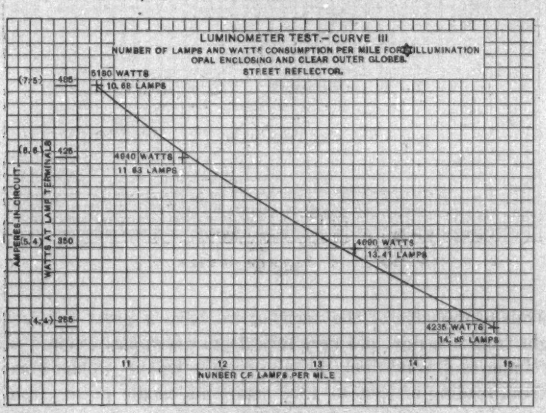


Fig. 5.

hours, and is not noticeable as a variation to the casual observer. It is objectionable, however, for other reasons. In some lamps this variation is controlled by what is called a "compensating winding" which automatically adjusts the relation between the shunt and series coils as the lamp heats up.

For such lamps we may say that the mean hemispherical light is practically constant, as the voltage at the arc does not materially change. Thermostats have also been employed to accomplish the same result, but they have not proved entirely satisfactory, and in some localities they require a summer and a winter adjustment.

WANDERING ARC.

The second variation of importance in open arcs is caused by wandering of the arc, due primarily to the non-homogeneity of the cheap grade of solid carbons usually employed. When the arc

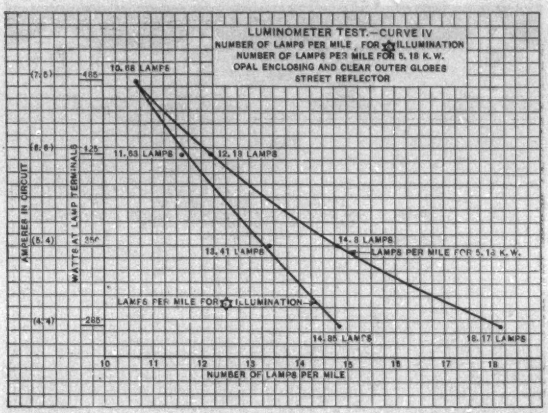


Fig. 6.

travels to the edge of the carbons we have a great volume of light from one side, and very little from the opposite side.

Under such conditions the photometer would probably show a freak reading of 1600 to 1800 maximum candle power from a lamp which would give about 1200 when the arc is co axial with the carbons.

This wandering also takes place in the enclosed arc lamp but it is not due particularly to the non-homogeneity of the carbons, because a high grade of carbon is employed, but it is primarily caused by the carbons burning flat in a globe practically free from oxygen and the arc wanders of necessity. The variation in

the light from this cause is not so great as in the open arc, but it is not altogether pleasant when clear globes are employed.

By using an opal-enclosing globe, the light is balanced and the variation is reduced to a satisfactory degree of steadiness and all shadows are obliterated (Fig. 3).

FLICKERING ARC.

A common complaint against the open arc is the flickering due in a measure to non-homogeneity of carbons, but mainly to the wind blowing the arc about. While the latter cause is not inherent in the arc, it is common practice in America to leave the

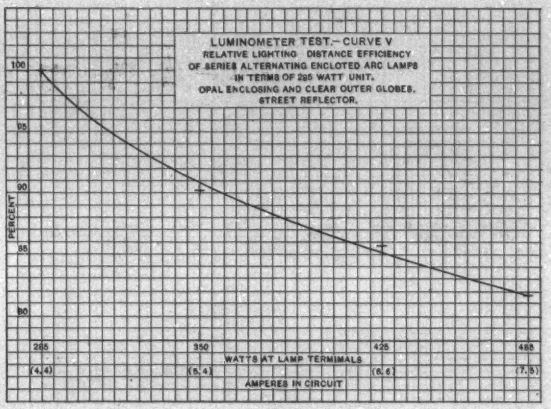


Fig. 7.

arc exposed to the wind and as this condition exists it seems reasonable to include it in the comparison.

High grade carbons are employed in the enclosed arc lamp and the arc is thoroughly protected from the wind so that flickering from the above mentioned cause is entirely absent.

ALTERNATING VS. DIRECT CURRENT ARC.

We are all more or less familiar with the low light-giving efficiency of an alternating open arc lamp. By the introduction of the enclosed lamp with its long arc and opal globe the difference in lighting efficiency between alternating and direct current has practically disappeared, so that the alternating enclosed arc

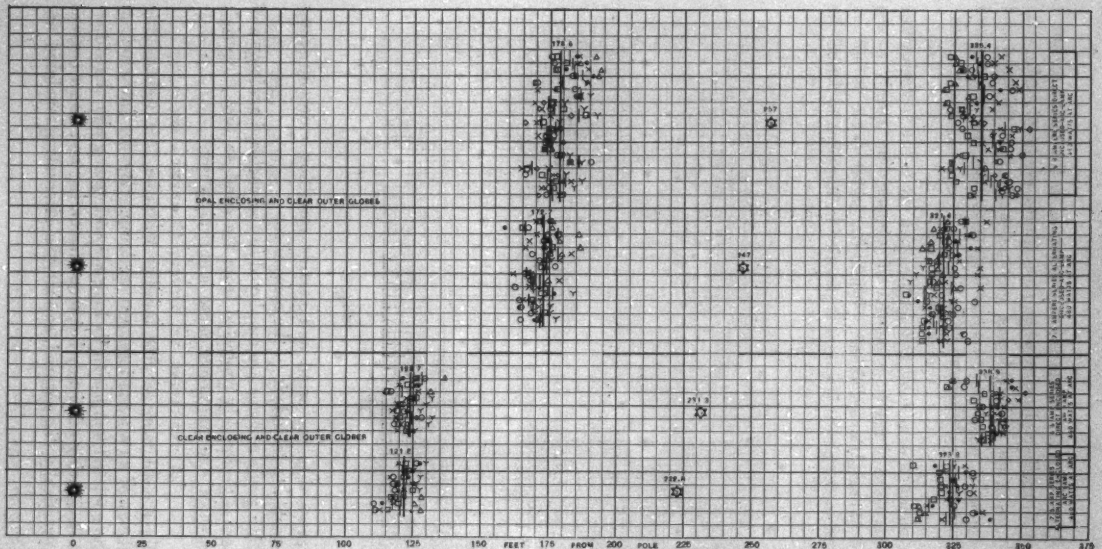


FIG. 8.—Luminometer diagram indicating that alternating and direct current arcs of equal energy will illuminate practically the same distance (Advantage of opal Enclosing globe).

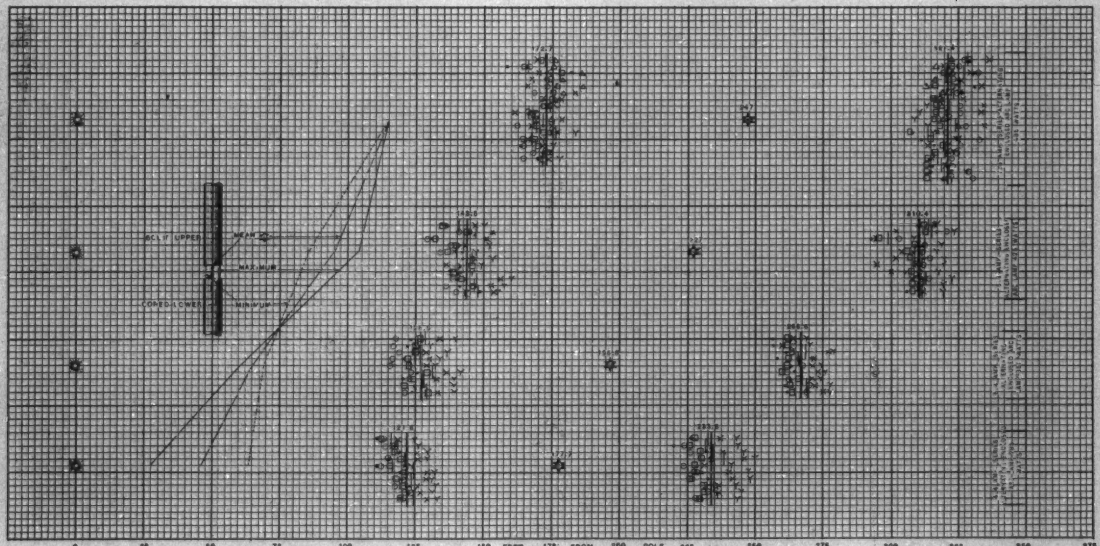

SPLIT UPPER
MAXIMUM
MAXIMUM
CONDUCTOR
MINIMUM
0
25
50
75
100
125
150
FEET
175
FROM
200
POLE
225
250
275
300
325
350
375

Fig. 9.

has about the same illuminating value as a direct current enclosed arc of equal watts.

It will be observed from the curves that the alternating arc does not give so high a candle power in any direction as the direct arc, but the distribution is slightly better and the effective illuminating value of the two lights at a point midway between lamps is about equal.

SMALL VS. LARGE UNITS.

In lighting a street we strive to light it uniformly so as to approach a moonlight effect. The employment of small units towards this end forms the basis of a most interesting investigation.

A photometer cannot be relied upon to give sufficiently accurate results for such comparisons, but I have found a small instrument called a "luminometer" very satisfactory. This instrument while not a scientific piece of apparatus is of considerable practical value, and it is used to determine the maximum distance a lamp will project a given illumination. A standard illumination of .006 of a candle foot was adopted throughout the tests. For convenience this was designated "star six illumination" and this convention is employed in all the diagrams. Tests taken on different nights and with different observers checked within 2 or 3 per cent. of the mean, and the results can be relied upon as being sufficiently accurate for all practical purposes.

It is quite impossible to lay down a fixed rule for the number of lamps which should be installed per mile, as the location is determined largely by the distance between cross streets the amount of light required and other local conditions.

Nevertheless, data on the relative lighting distance of various units can be used to advantage.

The accompanying diagrams show the relative lighting distances of 285, 350, 425 and 485-watt alternating enclosed arc lamps. The lighting distance efficiency of these lamps in terms of the smallest unit is respectively 100, 90.2, 85.7 and 81.7 per per cent.

For "star six illumination" midway between lamps we would install 10.7—485 watt units or 14.9—285 watt units per mile.

The former would consume a terminal wattage of 5,180 and the latter 4,235, resulting in a saving of nearly 1000 watts per mile with the advantage of four more brilliantly illuminated areas in the interval. Further, for 5,180 watts per mile we could in-

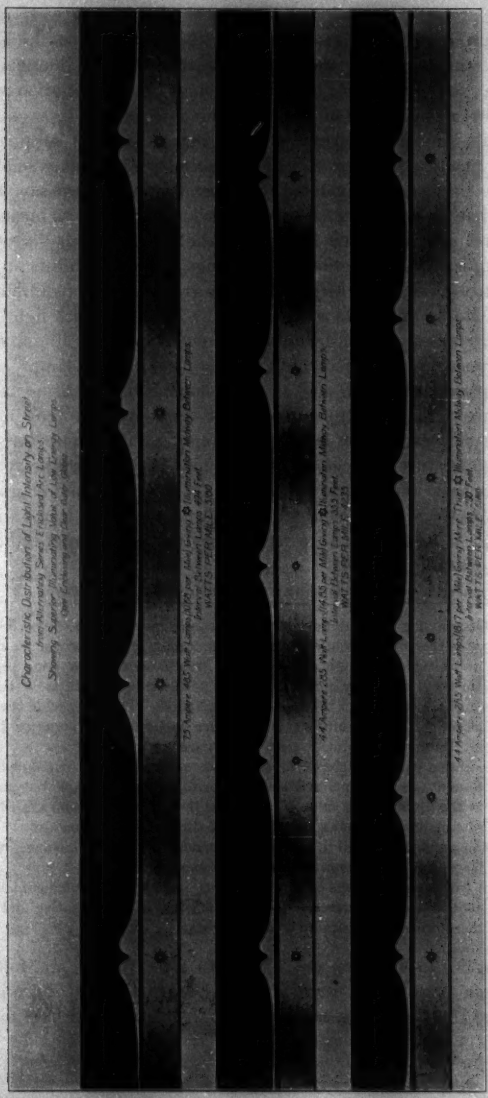

Characteristic Distribution of Light Intensity on Street
Arc Lamps
Showing Superior Illuminating Value of the Luminous Arc
Over Enclosed and Open Gas Lamps
15 Amperes 450 Watt Lamps 1000 per Mile Candle Power Illuminator Mixed Bohemian Lamps
Lamps Suspended Over Centre of Street 18 Feet
WATTS PER MILE 15,000
44 Amperes 1320 Watt Lamps 1450 per Mile Candle Power Illuminator Mixed Bohemian Lamps
Lamps Suspended Over Centre of Street 33 Feet
WATTS PER MILE 47,520
41 Amperes 1230 Watt Lamps 1867 per Mile Candle Power Illuminator Mixed Bohemian Lamps
Lamps Suspended Over Centre of Street 30 Feet
WATTS PER MILE 45,100

Fig. 10.

stall 18.2—285-watt units which would give us relatively eight more brilliantly illuminated areas in the interval, for the same expenditure of energy and with more than star-six illumination midway between lamps, therefore, from a light distribution point of view the advantage of the small unit is established.

While I am not prepared to state that a 285-watt lamp is the lowest practical arc unit, still I believe that this is about as small as can be satisfactorily operated for street lighting. I can say, however, that the argument for small units does not apply to incandescent lamps because one of the essential requirements for good lighting is the illumination of buildings and other objects on the street to a considerable height above the ground. This requirement is fulfilled by arc lights which flood the buildings with light and thus produce a general diffusion giving the street an illuminated appearance impossible to obtain with incandescent lamps, even when placed very high and at such short intervals as to make their use prohibitive from a point of economy. Moreover, the light from incandescent lamps in common with all comparatively low temperature sources lacks the luminosity or brilliancy obtainable from the electric arc and it therefore cannot encroach upon the arc where a considerable volume of light is required, although it fulfills in a very satisfactory manner a street lighting field essentially its own.

From the foregoing we draw the following conclusions:

First:—Open arcs give a higher maximum candle power than enclosed arcs of corresponding wattage, but the maximum candle power is in an undesirable direction and the light fluctuates through wide limits. Enclosed arcs give a higher candle power through the most useful angle from say 3 to 10° below the horizontal. The light from the enclosed arc is more uniform and steadier and generally superior from an illuminating point of view to open arcs.

Second:—Direct current enclosed arcs produce slightly higher candle power than alternating enclosed arcs of corresponding wattage, but so far as the illuminating value is concerned the two lamps are on a fair basis of equality both being superior to the direct current open arc.

Third:—Small unit arcs will illuminate proportionately greater distances than large units for a given expenditure of energy.

Fourth:—Incandescent lamps do not illuminate brilliantly to a sufficient height above the street surface to produce the effect of good lighting and are therefore not comparable with arc lights.

In justice to the open arc I wish to state that if we follow European practice, as carried out in large cities, of installing lamps at short intervals, say 80 to 175 feet apart and use more

complicated lamps which work within closer limits when carefully attended to, burn high grade carbons, protect the arc from the wind and use opal globes, the advantage of the enclosed arcs over open, from a light distribution point of view will somewhat disappear.

Aside from the mere question of light however there are other arguments for the enclosed arc, particularly with reference to maintenance, convenience and cost of operating which would throw the balance in its favor even if the open arc were raised to an equal illuminating plane.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902, President Steinmetz in the Chair.

THE INCANDESCENT LAMP OF TO-DAY.

BY JOHN W. HOWELL.

The incandescent lamp is too well known to you all to need an introduction or any description. It has been so often discussed before you that nothing remains to be said about it except as a part of the electric lighting system in the general discussion of the subject under consideration this evening.

The characteristic features of the incandescent lamp are its extreme simplicity, its absolute freedom from mechanism, the ease with which it can be lighted by means of a switch placed where most convenient, and its adaptability to low candle units and decorative effects. These features and the fact that it consumes no oxygen, yields no gases and has no flame, have won for the lamp its great popularity.

The incandescent lamp is adaptable to any system of electrical distribution in use for any purpose. There appears to be no difference in its operation on direct or alternating current, provided the latter has a frequency of 25 cycles or more per second. It is usually operated on constant voltage circuits, but gives even better results when operated at constant current, as the increase in resistance of the filament with use increases the watts consumed, and thus causes the lamp to maintain approximately its initial candle power throughout its life.

For street lighting, incandescent lamps are operated many in series on high voltage circuits of constant current. They are also made for burning directly in series with arc lamps.

The incandescent lamp is adaptable to those voltages which are generally considered safe for interior use. Two kinds of

carbon are used in making filaments and the best results require the proper combination of the two kinds. The specific resistance of these two kinds of carbon limit the voltage of lamps of a given candle power and efficiency in which this proper combination can be made.

Lamps for a higher voltage than will permit the proper combination of the two kinds of carbon may be made with less of the graphitic coating which has a low specific resistance, or entirely of the base carbon, but in either case the lamp should be operated at lower temperature to give equally good life and candle power results.

The best results are obtained with lamps of not higher than 120 volts—250 volts being now regarded as the maximum desirable voltage, and at this point there is an increase of about one-half a watt per candle for equally good results.

The efficiency of an incandescent lamp depends upon the temperature of the filament—the higher the temperature the better the efficiency and the shorter the life. Lamp efficiencies are usually stated in watts consumed per horizontal candle. The commercial limits are between $2\frac{1}{2}$ and 4 watts per English candle, or about 120 per cent. of these figures if spherical candle power is considered, the $2\frac{1}{2}$ watt lamps being used where electricity is expensive and regulation good, and the less efficient lamps where electricity is less expensive or regulation is not so good, or where other considerations demand a longer useful service from the lamps.

The color of the light from an incandescent lamp depends entirely upon the temperature of the filament, the higher the temperature the more nearly white the light becomes. The color of the light generally is yellow. Weber observed that the first visible radiations from a filament as it was heated came not in the red region of the spectrum, but in the yellow region, where the maximum radiation occurs when the lamp is at high temperature.

Dr. Nichols observed that carbon has a selective radiation in the yellow region of the spectrum, the radiations there increasing faster than radiations in the other parts of the spectrum.

The use of higher efficiency lamps is becoming quite general, very few 4 w. p. c. are now used for multiple lighting, while a few years ago no lamps of less than 4 w. p. c. were sold. This is due to the improvement in quality of the lamps and also to

better regulation of current. High efficiency lamps are more satisfactory than low. The filament being smaller, the bulbs blacken less and being hotter they break before reaching very old age. Low candle power lamps are also coming into more general use. The demand for these has increased very considerably in the last two or three years. The use of lamps for decorative effects and for special work of various kinds has increased the usefulness of the lamp and added to its popularity.

HARRISON, N. J., December 7th, 1901.

A paper read at the 150th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902, President Steinmetz in the Chair.

A NOTE ON AN ACETYLENE-IN-OXYGEN FLAME

BY CLAYTON H. SHARP.

In the conclusion of a report made to this INSTITUTE in 1896 by a sub-committee on Standards of Light of which Professor Nichols was chairman, it was stated that the sub-committee had in hand the investigation of a possible standard in which a pure gas, burning in a pure atmosphere should furnish the constant flame required. Since these investigations, which were being carried on by myself, have now been at a standstill for some time, this note is presented with the hope that it may be of some interest.

The idea underlying the work was to produce a flame which should be isolated from fortuitous outside influences, such as atmospheric purity and moisture content, which have so large an influence on ordinary flames.

A long series of experiments was conducted on a flame produced by the combustion of a mixture of equal parts of acetylene and hydrogen in an atmosphere of oxygen. The special burner employed gave a flame long, slender and of great brilliancy and steadiness. It was found, however, that its intensity was not reproducible from pressure measurements made on the gases. This was attributed to the fact that the acetylene-hydrogen mixture was stored over water. Since the solubility of these gases in water is not equal, and their temperature coefficients of solubility are not the same, the relative proportions of the two gases in a mixture so stored would not remain constant. Thus the first requisite of a standard of light, namely a fuel of perfectly definite composition, was lacking.

The reason for adopting the acetylene-hydrogen mixture instead of pure acetylene as a combustible had been that, with the burner employed, pure acetylene deposited graphitic carbon about the jet with such rapidity that the flow of gas was seriously obstructed after only a moment's burning. With the diluted gas this did not take place. After the failure of the mixture to yield the constant flame required, experiments were made to determine what form of burner would permit the pure acetylene to be used. This was found to be as shown in Fig. 1.

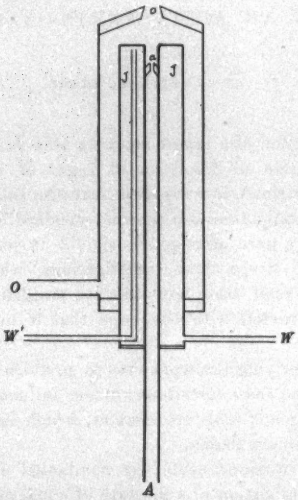


FIG. 1.

The acetylene passes through the tube A which is surrounded by the water-jacket J in which a circulation of water is maintained to keep the acetylene tube cool, and issues at A. The oxygen enters at O a concentric tube, and issues through o in a stream about the stream of acetylene. The water-jacket is carried above the acetylene jet so that a mixture of the two gases, and consequently combustion takes place only after the acetylene is well away from the jet from which it issues. With this arrangement there is no troublesome deposit of carbon and the experiment can be carried on indefinitely.

The flame so produced is capable of enormous variations according to the relative supplies of the gases. When the oxygen is not turned on at all, the flame is tall, unstable, murky and smoky. With increasing supply of oxygen, the flame shortens and increases in whiteness, brilliancy and luminous intensity. It also becomes stable and is little affected by drafts. If the increase in oxygen supply is carried beyond a certain point, the luminous intensity begins to fall off, due to the non-luminous

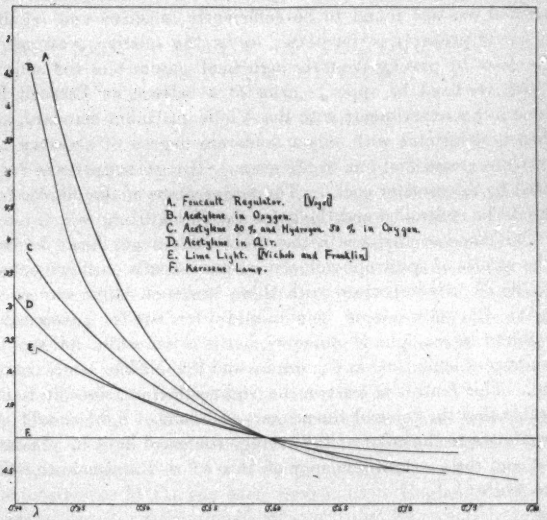

A. Foucault Regulator. [Vogel]
B. Acetylene in Oxygen.
C. Acetylene 50 % and Hydrogen 50 % in Oxygen.
D. Acetylene in Air.
E. Lime Light. [Nichols and Franklin]
F. Kerosene Lamp.

FIG. 2.

combustion of a larger proportion of the acetylene, until with a large excess of oxygen the flame becomes almost entirely blue.

Barring practical difficulties, the intensity of this flame should be definable as follows: With a given rate of flow of the gases, the height of the flame should be a given one, and the luminous intensity of the flame as a whole should be a maximum, and the luminous intensity of a portion of the flame isolated from the rest by a horizontal slit of a given width in a screen placed in front of the flame in such a way that the amount of light passing through

the slit should be a maximum, would then be perfectly fixed. The criteria mentioned are not all independent ones, but serve as checks on each other and increase the certainty with which the flame can be reproduced.

In my experiments I measured the height of the flame by projecting an image of it on a graduated screen. To measure the flow of the gases a diaphragm with a very small opening was interposed in each feed pipe and the gas pressure behind was determined by inclined tube manometers filled with alcohol. This method was not found to be sufficiently sensitive and reliable. It would probably be far better to fix the relative pressures of the gases by passing them through small gasometers the bells of which are fixed to opposite arms of a balance, as Petavel[1] has done in his experiments with the Violle platinum standard, and then to determine with only a moderate degree of accuracy the absolute pressure of one of the gases. The gas supply was regulated by micrometer cocks. The temperature of the diaphragms should be controlled and the gases should be dried.

The flame so produced is the most brilliant gas flame known. The results of spectrophotometric measurements on it are shown in Fig. 2 in comparison with those made on other sources of light. Its color adapts it admirably for use as a secondary standard in arc light photometry, but it is too white for the incandescent lamp, just as the candle and the Hefner lamp are too red. This fault is at least in the right direction, since it is desirable that the color of the primary standard of light should approximate to the color of the average source of light in practical use, and the constant tendency of this color average is towards the white.

1 Proc. Roy. Soc. Vol. LXV, p. 481, 1900.

A paper read at the 150th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902, President Steinmetz in the Chair.

THE PRESENT STATUS OF THE QUESTION OF A STANDARD OF LIGHT.

BY CLAYTON H. SHARP.

The situation as regards a standard of luminous intensity has shown in recent years a marked tendency towards simplification and unification. A number of standards or would-be standards, which were formerly taken seriously, have disappeared from practical use. Of the various candles, the British candle is the only one which survives, and the practical use of it is steadily decreasing. The Carcel lamp is held in much less esteem than formerly. Practice is settling down to the selection of one of two classes of standard, either the pentane standard in one of its forms, or the Hefner amyl-acetate lamp.

The small 1 C. P. and 1½ C. P. pentane lamp has proven itself worthy of confidence as a result of thorough investigation in the Reichsanstalt. The 10 C. P. pentane lamp is coming into very extensive use by the gas men here and in England, and commends itself by its simplicity of operation, by its relatively high intensity and, as far as is known, by the constancy of its indications. Unfortunately there is on record no such careful investigation of its properties in this particular as has been made for the smaller pentane lamp and the Hefner lamp.

If gas practice is looking more and more to the pentane standard, electrical practice is looking towards the Hefner lamp. The careful study made in the Reichsanstalt, the adoption of it officially in Germany, the resolutions in its favor by this INSTITUTE and by the Geneva Congress of 1896 have served to popularize it and to intrench it strongly.

While the facts enumerated show that great progress, it is not to be assumed that a satisfactory solution of the problem of a standard has been reached. A standard must be as nearly as possible a common denominator of the sources of light in ordinary use. No one integrated source of light can be in all strictness a common denominator for all, on account of the existing differences in quality or color. That light most nearly fulfils this condition which most nearly approaches in color the average color tone of the sources of light in use to-day. Now this is much higher than it was a few years ago, due to the extensive introduction of whiter hued sources of light. The standards referred to above stand, as far as color is concerned, about at the bottom of the list, and from this point of view are as bad as possible. Photometric comparisons with them of most modern lights are very uncertain, and the results are misleading in that they do not give to the whiter sources credit for the greater visual acuity per candle power which is their due.

It follows that a standard of light of considerably whiter hue than the present ones would be intrinsically better if of equally good qualities in other respects, and it is towards the definition of such a standard that efforts should be directed.

Quite a good deal has already been done in this line. A notable advance has been made by Petavel[1] in his investigation of the Violle platinum unit. He has indicated the precautions which must be taken to secure good results, and has demonstrated that the limits of error may be made quite narrow. The color of this standard is quite good. Violle has stated that it is very similar to that of the acetylene flame, but this statement does not seem to be entirely consistent with the known fact that platinum can readily be fused in the acetylene flame.

The studies by Paschen and by Lummer of the theoretically "black" body have indicated a method by which a perfectly definite radiating surface can be secured, and it needs only a sufficiently accurate method of defining the temperature of such a surface to give us a standard of light. Since, however, the luminous radiation from such a surface increases as a high power of the temperature, a sufficiently accurate method of temperature definition cannot easily be found.

1. Proc. Roy. Soc., Vol. LXV., p. 481, 1900.

Among the ordinary sources of light, the acetylene flame probably approaches most nearly in color to the average hue. The ease with which this gas can be produced in a good degree of purity and the steadiness and manageability of its flame also commend it for use as a standard. Violle[1], Fessenden[2] and Féry[3] have made independent propositions to this end, but no definite standard as yet been the outcome.

Fessenden showed how a stable flat flame can be produced with this gas, employing the method of the converging jets now in common use. He found the flame to be very steady and moderately immune from outside influences. Such a flat flame, with the light from its edges screened off, has been used very successfully by Professor Nichols[4] in his spectro-photometric investigations of the radiation of carbon. The flame was controlled by measurements of the pressure of the gas.

The proposition of Féry looked to the use of a long, slender flame. He used a bit of thermometer tubing of internal diameter of 0.5 mm. as a jet. With this he found that the luminous intensity of the flame was proportional to the flame height between the limits of 1 cm. and 2.5 cm., that is, he substituted for control by pressure measurements, control by measurement of the flame height.

What is now known of the properties of the acetylene flame indicates that a search for the best method of producing and defining an invariable acetylene flame would be fruitful of valuable results.

It has been proposed to employ as a standard flame one in which a pure gas burns under standard conditions in a pure atmosphere, both of know chemical composition. A practical method of burning pure acetylene in an atmosphere of pure oxygen has been found, as well as direct and interchecking methods for the control of such a flame, but the investigation has not led to any definitive result.

Until a more satisfactory standard is introduced, photometrists are practically limited to the choice of either a pentane standard

1. *Comptes Rendus*, Vol. 122, p. 79, 1896.
2. TRANS., A.I.E.E., Vol. XII., p. 500. 1895.
3. *Comptes Rendus*. Vol. 126, p. 1192. 1898.
4. *Physical Review*. Aug. and Oct., 1901.

or the Hefner lamp as primary standards. An incandescent lamp carefully seasoned and measured furnishes for most purposes a thoroughly satisfactory secondary standard, and we are looking forward to the time when the National Standardizing Bureau will establish an authoritative standard and will measure and will certify to lamps sent to them for this purpose.

A paper read at the 159th Meeting of the American Institute of Electrical Engineers, New York and Chicago, January 3, 1902, President Stevens in the Chair.

ELECTRIC GAS LAMPS AND GAS ELECTRICAL RESISTANCE PHENOMENA.

BY PETER COOPER HEWITT.

On a former occasion I had the honor of showing to the members of the INSTITUTE lamps utilizing the conductivity of gas for illuminating purposes, including experiments illustrating certain laws of conductivity of gases, and I also presented curves directing attention to various characteristics. It gives me pleasure to-night, while showing lamps in operation lighting this room, to describe some of the phenomena exhibited by the lamp and to indicate some of the difficulties encountered in determining the relative values of the resistances therein.

The mercury gas lamps exhibited to-night are operated on the standard Edison 118-volt direct-current circuit installed in this building; lamps of this class consume amounts of current varying from 1 to 6 amperes, and the efficiency is approximately $\frac{1}{3}$ watt per spherical candle power. Under better conditions as high an efficiency as $\frac{1}{4}$ watt per spherical candle power has been obtained, determined by careful and accurate measurements. Measurements were made by measuring sections of the lamp varying in length from $\frac{1}{4}$ of an inch to 3 inches, shielding the lamp and leaving a slot in the shield of the length mentioned, and measuring the light transmitted through the slot. These measurements have been made with lamps of various diameters. Dr. Max von Recklinghausen has made independent measurements, comparing the illuminating value of the lamps with incandescent lamps of equivalent rated candle power, and the results of such tests agreed remarkably well with the measurements obtained upon photometers.

I have made lamps with diameter of bore less than $\frac{1}{8}$ of an inch and as large as 3 inches, and from less than 3 inches in length up to over 10 feet, giving from less than 10 candles up to fully 3,000. Lamps of very small bores give more trouble in manufacture and operation than those of moderate size. Lamps of innumerable shapes and dimensions have been constructed and great variation of candle power for various diameters obtained. There appears no reason why lamps may not be made of any size required and of any desired candle power per inch within wide limits, the only limitation appearing being that imposed by softening of the glass when too many candle power per inch are produced. The general rules established regarding their operation hold good in so far as examined, and it is possible to predetermine with almost absolute exactness the voltage, current consumption and candle power of a lamp when the manufacture is perfect.

The light produced by pure mercury gas comprises orange-yellow, lemon-yellow, green, blue, blue-violet and violet; and although all shades of these colors may not be present, their absence would not be so seriously felt were it not for the absenee of the red. For some purposes the lack of red in the spectrum is objectionable, but for many uses it is a positive advantage.

For shop work, draughting, reading and other work where the eye is called upon for continued strain, the absence of red is an advantage, for I have found light without the red is much less tiring to the eye than with it. It is possible to transform some waves of this light, especially the yellow light, into red light, and thus in a measure to overcome this defect where required for general indoor illumination. A moderate amount of ordinary incandescent light interspersed with the mercury gas electric light serves to supply the deficiency, and the mixture may be made most satisfactory. For ordinary street lighting purposes the mercury light is available even without the red, and it should be noticed that this light has very great penetrating power and seems to be effective through greater distances than an equivalent amount of measured candle power from the ordinary incandescent lamp. This may be due to the fact that the waves of the red light are less penetrating than those waves which are present in the mercury light, and hence the least valuable portion of the spectrum having such illuminating effects is omitted and the energy is practically expended in the more useful portions of the spectrum.

I have made lamps in which this color objection has been overcome, sacrificing on some occasions the extremely high light efficiency obtained in this particular lamp. Without doubt lamps of this type will be produced whose light will be even more beautiful than this light is objectionable; in fact, I have produced very beautiful and becoming light. Every gas gives its own particular spectrum when traversed by current, only part of which is visible, and that one having its spectrum richest in the visible portion is the most efficient for service as a lamp. Each develops its own color peculiarities and presents its particular electrode phenomena, chemical and physical, but I am convinced it is only a matter of patient work to render many gases practically available as light-giving media. When it is considered that this light, when obtained with mercury gas, has an efficiency at least eight times as great as that obtained by the ordinary incandescent lamp, it will be appreciated that it has its use in places where lack of the red is not important, for the economy of operation will much more than compensate for the somewhat unnatural color given to illuminated objects.

I would like to state some of the phenomena that had to be unravelled before it was possible to establish the laws governing the operation of electric gas lamps. The conductivity of the gas of the lamp, which is the most important factor, is dependent upon the diameter of the gas column, the length of the gas column, the density of the gas in the column and the resistance factor of the particular gas; with these must be considered the resistance at and about the respective electrodes to obtain the total resistance presented by the lamp. In determining the relative values of these it was assumed that the resistance of the gas column would vary directly as the length; this has so far proved to be true. From the results of a great number of experiments, and from some particular ones, I was able to demonstrate that the resistance varied inversely with the diameter; not as a square, as in metallic conductors, but very nearly as the first power. It is very difficult to obtain identical surroundings for lamps of different diameters, and I am of the opinion that any discrepancy that occurs is due to difference of environment. I was able to demonstrate that the resistance varies inversely with the quantity of the current passed, which means that the lamp requires a constant voltage unless some change takes place. The voltage across the terminals of the lamp is modified by the density of the gas,

a gas having a density of maximum conductivity or a certain definite amount of matter and molecular movement best suited for conduction. Beyond the point of maximum conductivity the resistance appears to increase absolutely directly with the density, but I wish to state that my means of measuring at these low densities were not sufficiently accurate. The density is an entirely controllable factor, and is one of the best means of controlling the voltage. The laws above stated appear to hold good as to gases, generally.

The electrode resistance at the positive, providing there is no alteration of the chemical or physical condition of the electrodes, may, from a practical standpoint, be regarded as being very slight and will be neglected for the present.

The negative electrode resistance offered very great difficulties and required long and patient experimental investigation. I found that it consisted of a variety of factors, and I will briefly direct attention to those which appear to have the more important bearing upon the operation of the lamp. There is a reluctance to the initial passage of current which appears as if self-created by the current—as if by induction. Upon increasing the voltage applied thereto, current passes to a very small extent and thereupon there is a fall in resistance. To increase this small amount of current the voltage must be still further increased. On further increase of current this resistance apparently ceases and there is an enormous decrease of voltage. This resistance apparently do s not exist when chemical or physical alteration occurs at the electrodes.

When the last named resistance is overcome by reason of passing current, a flame may be noticed proceeding from the negative electrode in a direction perpendicular to the surface from which it issues. If this flame meets the current in a right line, that is to say, projects in the direction of the flow of the current at the point of meeting, the total resistance of the lamp is materially greater than when the flame proceeds in a direction at an angle to the flow of the current.

When the flame is proceeding from the negative electrode at an angle to the line of the current, then the resistance at the negative electrode, under the conditions which are established is reduced, and practically speaking, the principal and controlling resistance of the lamp is then located in the gas-path proper.

The reluctance to starting is greatly modified by charging the surface of the lamp exterior to the negative electrode positively, and also in a less degree by dissipating the charge that collects there. It is for this reason that the lamps have a conducting band exterior to the negative. This resistance may also be modified by charging and discharging the lamp with a high voltage current.

I may here add that these initial resistances to the passage of current may be overcome by an impulse of high potential, as by the discharge of a reactive coil.

Electrical relations, as well as chemical, exist between the various kinds of gases used and electrodes of different materials, so that the presence of some other matter, "foreign matter," may bring about a total change of conditions and phenomena which normally should exist at the negative electrode in a state of purity. These conditions give rise to new and unexpected phenomena, and phenomena of great importance are brought into existence at the positive electrode. In the practical manufacture of the lamp, when abnormal conditions arise, that is to say, when other phenomena than those above outlined appear, or those above outlined do not appear, it is customary to attribute them to the presence of "foreign matter."

From what has been stated, it will be seen that the problems, which had to be solved to produce a lamp, comprised, among others, not only the determination of the conductivity of the gas column, involving the relations of the length and diameter, but determining the relative values of the other different factors of the electrical resistances, resistance at the electrode, etc.; determining the conditions accompanying varying densities, the variations in the conductivity with respect to the amount of current flowing; also methods of finding a pure gas with stable chemical and physical conditions within the lamps, and also determining the relations of the electrodes and gas with respect to each other under operating conditions.

In one experiment shown upon the former occasion referred to, the initial resistance to the passage of the current was illustrated and the electrical leak through this resistance was measured; but at that time no attempt was made to point out the several resistances or factors thereof which have been referred to above.

In some particular forms of lamp the resistance at the negative electrodes has been availed of to render the negative electrode itself a source of light. Such conditions were established that no physical or chemical change took place at the negative electrode, and it developed that the electrode could then be heated to any desired temperature. Iron electrodes under these conditions may be maintained at a very high temperature and give off considerable light, the electrode itself being then the chief source of light. I even succeeded in melting platinum and maintained it in a molten puddle.

I might mention an interesting negative electrode experiment where an ordinary lamp about 30 inches in length contained a rod of metal one-eighth inch in diameter, projecting from the mercury negative to an eighth of an inch of the positive electrode, which was located as usual, and a movable bridging piece permitted bringing this rod into electrical connection with the positive. On forming contact and breaking, the current shoots to the mercury negative, although the total resistance over the lamp requires 60 volts with about two amperes passing, while that of the rod was negligible with respect to ohms.

The presence of slight impurities in the lamp serves to vary the resistance to starting in a very marked degree. Under some conditions impurities or "foreign matter" facilitate conduction, whereas under other conditions "foreign matter" serves to greatly increase the resistance.

Referring again to the flame occurring at the negative which is present while the lamp is in operation, it may be stated that the direction of the flame is largely, if not entirely, independent of the direction of the current, and is determined by the plane of the surface receiving the current. The direction of the flow of the current to that surface is, generally speaking, through the shortest path from the positive electrode, so that if the entrance plane of the negative electrode surface be out of the perpendicular to the flow of the current, then the flame may be made to proceed in a direction out of the path of the current and thus will not interpose its resistance to the current flow. In some of the types of lamps shown here to-night, the surface of the mercury constituting the negative electrode, as will be seen, does occupy such a position with relation to the path of the current, and the flame proceeds in a line out of the path of the current. In some of the lamps, for the purpose

of causing the position at which the current passes into the negative electrode, to remain fixed and the flame regulated, the metal leading-in-wire is carried to a point at the surface of the mercury, and the path of the current once being fixed upon this point, remains there instead of wandering about the surface of the mercury, the current entering the meniscus. The flame may be deflected and its position controlled by the use of a magnet when so desired. Where no point is used there is a tendency for the current to wander and burrow, as it were, into the body of mercury. This results in temporary depressions, so that the flame may proceed from the walls of these depressions in a direction at an angle to the direction taken by the current, but the wandering of the current about the surface of the mercury will necessarily cause a constant shifting of the direction of the the flame and cause variation in the resistance of the lamp.

I have used other gases than the vapor of mercury as the gas path, but mercury is more convenient for general experimental investigation for many reasons, among them the fact that as a negative electrode, its resistance is stable, the readiness with which the alteration of its condition may be brought about, the high efficiency of a mercury gas as a light giving medium, and also the fact that it can easily be obtained in a fairly pure state.

NOTE.—For previous experiments referred to above, see *Electrical World and Electrical Engineer*, April 27, 1901; *Scientific American*.

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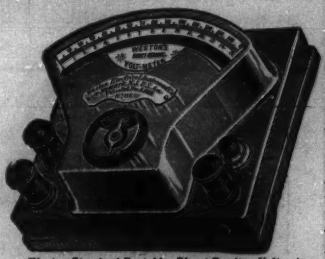

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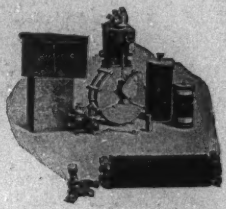

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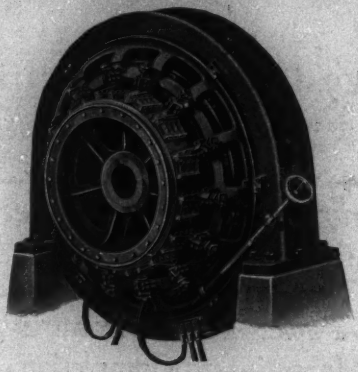

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